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HOW THE

GREAT PREVAILING WINDS

AND

OCEAN CURRENTS

ARE PRODUCED,

AND HOW THEY AFFECT THE TEMPERATURE AND DIMENSITY OF LANDS AND SEAS.

BY

C. A. M. TABER.

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PREFACE.

In the following pages, I have endeavored to give what I consider to be the principal causes which produce the great prevailing winds and ocean currents. The reason why I have thus sought to set forth my views, is because, after many years experience on the several oceans of the globe, I found that the generally accepted theories were not in harmony with the world-wide operations of nature,—such theories being adapted only to certain areas of oceans and continents, and not applicable to larger portions of the globe, where the great movements of the atmosphere and ocean are not concordant with the generally accepted explanations. During the time my attention has been directed to the great prevailing winds and ocean-currents, I have been impressed with the manner in which they affect the climate of the different zones; while further consideration led me to conceive how such winds and currents, owing to the formation of continents and oceans, have been able to bring about the wonderful climatic changes

which have taken place during long periods of time on different parts of the earth, causing in the high latitudes great ice periods, and intervening eras of mild weather; and also during such periods causing submergences and uprisings of extensive lands. My views being different from those who have written on such matters, I was induced to publish them in the spring of 1879, and again in the spring of 1881, but some of my statements required further explanation; therefore I again set them forth with such additional considerations as may serve to support my earlier essays.

C. A. M. TABER,
Wakefield, Mass.

HOW THE GREAT PREVAILING WINDS AND OCEAN CURRENTS ARE PRODUCED, AND HOW THEY AFFECT THE TEMPERATURE AND DIMENSITY OF LANDS AND SEAS.

For many years, navigators, and also dwellers on the land, have made observations on different parts of the earth to ascertain the true extent, direction, and velocity of the great prevailing winds. The observations thus made have shown that the principal air-currents of the globe are found to be moving in contrary directions along the different zones; the winds of the torrid zone moving generally with the sun, towards the west, while the winds of the temperate zones generally move in an opposite direction, towards the east.

In order to explain the cause of these great prevailing movements of the air, various theories have been published; not only to show why such air-currents prevail, but also to point out their effect on the waters of the sea, as well as on the climate of different countries.

The theory now generally accepted for explaining the causes which produce the great air-currents was, as far as I know, perfected by Hadley (as recorded in the Philosophical Transactions of the Royal Society 1735). This widely adopted theory, as now explained, is declared to consist in "a great system of surface-currents continually streaming out of bands of high atmospheric pressure towards a belt of low pressure around the equator on one side, and towards the poles on the other, and of upper air-currents continually flowing away from the low-pressure areas,—a system set in motion by the greater warming of the equatorial regions by the sun, and consequent low pressure of the atmosphere there, than in the regions on either side. It might be that those assumed currents with an uninterrupted circulation should

have a direct north and south course; but, owing to the diurnal rotation of the earth, an object at the equator is carried along with far higher speed than an object nearer the pole. Hence when a current of air travels away from the equator northward or southward it moves in a region of less velocity, yet at the same time carries with it part of its equatorial rapidity of rotation. Now as the earth rotates from west to east, a current of air flowing from the tropics north or south across the high latitudes, would be forced towards the east, thus causing a south-westerly wind in north latitude, and a north-westerly wind in south latitude. On the other hand, the air which travels from the higher latitudes towards the equator is always getting into regions where the speed of rotation increases; therefore it lags behind, causing a north-east trade-wind north of the equator, and on the south side a south-east trade-wind, the two winds meeting at or near the equator, where their vapors are collected, thus producing a calm belt of rainy weather encircling the earth."

In this theory, so commonly received, it will be seen that equatorial heat is declared to be the original mover of the atmosphere, while the rotation of the earth only acts on air-currents while being moved by equatorial heat in a northern or southern direction. So far as this theory refers to the action of equatorial heat, it is true only on widely separated portions of the tropical zone, where the conditions are favorable for such action. On such areas, it appears that equatorial heat does attract the colder and heavier air from the higher latitudes; but there is a lack of evidence to show that air thus attracted is left behind through the diurnal rotation of the earth, or that equatorial heat is the principal cause of the movement of the atmosphere of the tropical latitudes; and it is because of this lack of evidence that other theories have been advanced to account for the great prevailing winds of the tropical latitudes which move so constantly from the eastern to the western sides of oceans.

In the reports of the Philosophical Transactions of the Royal Society, as early as 1686, Dr. Halley said that "some people had been inclined to propose the diurnal rotation of

the earth on its axes, by which as the globe turns eastward the particles of air being light are left behind; this he dissented from because of the westerly winds which prevail on the coast of Guinea. But he gives no explanation why such winds blow from the westward, except from the exceedingly rarefied condition of the heated air on that portion of the African coast. Halley thought the reason why the prevailing tropical winds blew mostly from the east towards the west "was because the air which is less rarefied or expanded and consequently more ponderous must have a motion towards those parts where it is more rarefied and less ponderous to bring it to an equilibrium; and, secondly, the presence of the sun continually shifting to the westward, that part toward which the air tends by reason of the rarefaction made by his greatest meridian heat, is with him carried westward, and consequently the whole tendency of the body of the lower air is that way; thus a general easterly wind is formed, which being impressed on all the air of the vast ocean the parts impel one another and so keep moving until the next return of the sun." With this barren explanation he further said, "it is likewise very hard to conceive why the limits of the trade-winds should be confined to about 30° latitude all around the world; and that only the north Indian Ocean should be subject to monsoons, and that in the southern there should be a constant easterly wind." Dr. Halley's views appear to us true in the main, and they probably would have been more generally accepted were not his explanations so barren that they appear little better than mere statements. But they were written nearly two hundred years ago, long before a correct knowledge of the true extent and direction of the prevailing winds of the globe existed. Even a half century later, when Hadley had perfected the theory now so prevalent, the impressions then formed of the real movements of the prevailing air-currents were far from correct, as his explanations clearly show. Yet his theory made such a deep impression on the majority of minds seeking information in that direction, that they have not been in a condition to seek out the truth, even in regard to the true course of the winds

which blow over the ocean so constantly at variance with Hadley's theory.

Lieut. Maury neglected to profit from the experience of hundreds of navigators, simply because it was conflicting with the lesson he had learned in early life. Thus while he and other prominent writers on meteorology have sought to strengthen Hadley's theory, other learned writers, seeing the incompatibility of his explanations with the true workings of nature, have framed other theories to account for the great prevailing winds.* But the opinions of such writers have not been widely accepted, from the fact that there seems to be no way consistent with man's experience for proving their truthfulness. Still their writings are valuable as being ingenious and able exponents of the errors of the theory accepted to-day. But though the object of this treatise is to explain my own views, yet, while endeavoring to show how they harmonize with the actual operations of nature, I shall meanwhile expose what I consider to be the principal error of Hadley's theory because of its wide acceptance.

This theory, as I have briefly shown, maintains that the air of the high latitudes is attracted towards the equator through the greater warming of the equatorial regions by the sun, and the consequent low-pressure there, than in the regions on either side, and that the assumed air-currents thus caused should have a direct north and south course; but owing to diurnal rotation the surface of the earth rotates with far higher speed near the equator than in latitudes nearer the poles; therefore the air which moves from the high latitudes

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* William Leighton Jordan, in his work entitled "The Ocean," endeavors to show how the currents of the air and ocean are caused by vis-inertiæ, in connection with what he terms astral and terrestrial gravitation.

John Knox Laughton, in his work on "Physical geography in its relations to the prevailing winds and currents," declares that the westerly wind is the principal atmospheric current of the globe, and is prevalent at the surface of the globe in the temperate zone, and frequent on and near the equator, and almost constant in the upper regions of the atmosphere. This he says is caused through the action of the heavenly bodies and preëminently of the sun and moon, and not by a difference of temperature caused by the sun on different parts of the earth.

towards the equator lags behind, causing a north-east wind north of the equator, and a south-east wind south of the equator.

However correct this theory may appear on certain portions of the globe, it fails to coincide with observations made on extensive parts of tropical oceans far removed from land, the very places where it should be proved.

Such off shore waters, according to the experience of persons sailing over them, have no regular north-east and south-east trade-winds separated by a calm-belt, but rather, a prevailing easterly wind veering a few degrees north and south of east. Such is the direction of the prevailing winds of the tropical Pacific Ocean where removed from the influence of the American continent. The fact is, the equator and latitudes near it do not possess a decided space of rarefied air sufficient to attract the atmosphere of other portions of the torrid zone lying parallel with such latitudes, except in the vicinity of heated lands. The cold waters of the ocean moving from the high latitudes and meeting near the equator prevents inequalities of temperature in the torrid zone to a great extent.

The *Challenger* expedition, while crossing the tropical zone in the central Pacific near the longitude of 150° west, found when sounding 1000 miles south of the equator, the surface temperature of the sea to be 26°.4C., and at 33 miles south of the equator 26°C., and at 1200 miles north of the equator 25°.8C., while the variations in the temperature of the surface waters for the intervening latitudes were slight. The warm waters a thousand miles from the equator were found to occupy a thicker layer than at the equator. Such being the equal temperature of the waters of the tropical latitudes in mid ocean, and it is well known that the surface waters of the sea largely govern the temperature of the air lying over it, therefore there are no regular north-east and south-east trade-winds separated by an equatorial calm-belt extending across the Pacific Ocean.

On sailing over the North Atlantic in latitudes bordering the tropical zone, from mid ocean to the American shores,

air-currents are not usually found to be blowing towards the equator, their general movement ranging from the eastward, and more frequently from the equatorial regions than towards them. According to Lieut. Maury's sailing directions, navigators while crossing the North Atlantic tropical wind-belt in mid ocean, often report the so-called north-east trade winds blowing from the south of east. And after a long experience with the winds of this region I am convinced that such reports are true.

Judging from these facts, there is lack of proof to show that the easterly winds of the torrid zone are caused by the air being left behind while on its way from the high latitudes to the equator through the rotation of the earth, as described in Hadley's theory.

Still it is well known that on the eastern sides of the Atlantic and Pacific Oceans, in both the northern and southern tropical latitudes, the winds blow regularly towards the equator and meet in extensive calm rainy regions. The movement of such air-currents is probably caused through the influence of heated equatorial lands. The in-shore portions of such winds generally follow down the coasts of continents, while further off shore they gradually turn towards the west; so that when removed from the influence of land their general course is from east to west.

The reason why tropical winds blow from east to west across wide oceans, is because the principal differences in atmospheric pressure being caused by temperature, the daily passage of solar heat over wide lands and seas appears sufficient to give a prevailing westerly motion to the surface winds of the tropical latitudes. For when we consider the daily passage of the heat of the mid-day sun over the earth's surface, it appears that the air on the places passed over must be constantly cooling until the next rising of the sun, while the quicker heating of the air is performed in front of the sun from sunrise until the most heated part of the day. This diurnal heating and cooling of the lower atmosphere of the tropical zone causes an uneven atmospheric pressure towards the east and west. For it has been found from

numerous observations made within the tropics, that the lowest barometric pressure is generally during the hour of the greatest heat. So the heaviest atmosphere is found in the morning after the nocturnal absence of the sun. But between these extremes of atmospheric pressure barometric oscillations take place, which are supposed to be caused by watery vapor, yet they are not sufficient to change the general effect produced by the greater extremes of atmospheric pressure caused by temperature. Therefore the rarefied atmosphere caused by the vertical sun is the attractive point for the cooler air of the east and west. Thus it may seem that the attraction in front of the sun is equal to the attraction in its rear. But the attraction following the sun having twice as much more time to act than the opposing attraction in front of the tropical noon; therefore the last named attraction moves the air back a less distance than it is carried forward by the longer attraction, because in the shorter attraction in front of the sun the more hurried air meets with greater resistance from friction while passing over the earth's surface, besides the greater lessening of pressure in its rear to be overcome with an increased rate of speed. There is not a more important truth in physics than this. For the difference in favor of the most enduring air-current constantly creates powerful agents to increase its strength; for the prevailing attraction following the sun not only carries the vapors across tropical oceans to be condensed on their western shores, thus constantly setting free vast stores of heat, and thereby greatly adding to its power, but during such operations the surface waters of the sea gain a higher temperature on the leeward side of the tropical oceans, through their long exposure to the warm winds that sweep them westward; and furthermore, the heated lands lying west of tropical seas add still further attraction to strengthen the great primary air-current on its western course. Consequently the counter attraction in front of the sun being a retreating force, finds an opposing wind already in possession of places it passes over, which it must overcome before it can create a counter wind; which work it generally fails to accomplish, because in the torrid zone

it possesses little power to create auxiliary forces. Yet evidently it is able to weaken the prevailing wind. For it is a fact well known to navigators that the trade-winds in mid ocean generally lose strength as the heat of the day increases; their weakest point corresponding to the highest temperature. And it is through this counter-attraction in front of the sun, in combination with heated equatorial lands, that sufficient strength is obtained against the eastern shores of tropical oceans to overpower the easterly winds, thereby creating calms, counter-winds and monsoons. But the attraction following the sun maintains the greatest general influence on torrid seas; therefore, the greatest portion of tropical winds move on a western course.

In this explanation of the easterly winds of the tropics, it will be seen that the attraction which follows the sun and causes them to blow, is barely able to overcome the opposing attraction in front of the sun. But the first named attraction being somewhat superior is able to create helping agents which combine to give it power to control the direction of the winds throughout the greater portion of the torrid zone. This conflict with an opposing attraction, which under unfavorable conditions it cannot overcome, is the principal reason why it does not usually extend far outside of the tropics. The high latitudes being less exposed to solar heat, the diurnal variations in atmospheric pressure are proportionally less; in fact they were first discovered by Humboldt in the tropical latitudes.

Thus it appears that the attraction following the sun from east to west in the tropical latitudes causes an easterly wind to sweep around the earth, except where the attraction of heated lands combines with the opposing attraction in front of the sun, and thereby gains sufficient strength to overpower it; thus causing counter-winds, monsoons and calms.

The great primary wind of the torrid zone following the heat of the noonday sun from east to west across wide oceans, necessarily disturbs the atmosphere in latitudes outside of the tropics and more remote from the sun, and this disturbance naturally creates counter-winds. We see this per-

formed on the North Atlantic, where the prevailing winds, like the great aquatic currents, move around the mid ocean waters of the Sargasso Sea. The trade-winds, through the intervention of the eastern continent in the vicinity of the Madeira Islands, generally blow from the north of east; and while a portion of this air-current is attracted down the African coast to the rainy region against equatorial Africa, a still larger portion gradually turns towards the west, passing the Sargasso Sea on its western course, being attracted by the daily passage of the sun and the high temperature of the western tropical Atlantic. But on or before reaching the Gulf of Mexico a considerable portion of these winds frequently move towards the north-west, being gradually turned from their normal mid ocean course by mountain ranges, and attracted by the heated plains of North America; thus causing their vapors to furnish rain for the United States, and also to supply air displaced by winds which generally move eastward from the Rocky Mountains towards the North Atlantic. In these latitudes they are called the return winds; moving eastward across the ocean towards the shores of Europe, until a portion of the winds are attracted southward on the European side of the Atlantic to supply the air displaced by the trade-winds, which blow down the African coast past the Maderia Islands, thus uniting again with the great easterly winds of the tropics.

Under such conditions there can be no other prevailing movement to the surface winds of the high latitudes of the Atlantic, because the air attracted southward and westward past the Madeira Islands, and forming, as we have shown, the trade-wind of the North Atlantic, must be replaced by such surrounding atmosphere as can be the most easily attracted to fill the vacancy thus caused. The heated plains of Sahara refuse sufficient air to supply the trade-wind; and the atmosphere of Europe not being available, being largely attracted in other directions, therefore the air over the North Atlantic lying west of Europe is drawn eastward to fill the vacancy caused by the trade-winds of the Eastern Atlantic. Still, while a large portion of the air thus moving eastward

turns southward to supply the tropical winds, a considerable portion moves onward to the heated plains and valleys of Europe and Asia. Yet while on its way over the land it frequently turns southward through the valleys of Southern Europe, towards the heated plains of Sahara, so that the prevailing winds of the Mediterranean are from the northward.

In addition to the causes I have pointed out for creating the westerly winds of the high latitudes, it is evident that they are assisted by the attraction in front of the sun, it having a more concentrated power than the attraction following the sun; as I have before shown. Therefore it should act outside of the tropics, especially as the general atmospheric conditions are favorable for it, while the more diffused attraction following the sun would lose its commanding power on being weakened, and consequently easily overcome, particularly with the conflicting influences I have shown to be operating in the high latitudes. The winds which blow over the United States of North America show how the attraction in front of the sun gives a prevailing motion to the air. The prevailing westerly gales which sweep over its central and eastern lands and continue on at times across the Atlantic, are set in motion on the great plains which spread east from the Rocky Mountains. The eastern lands being heated by the rising sun earlier than the more western regions, causes the air to be attracted towards the east away from the Rocky Mountain range towards the Atlantic Ocean. That the attraction in front of the sun does cause such westerly winds appears evident on account of their frequent rising with the sun, and gradually losing strength on the approach of evening. This is because the air attracted east by the morning sun is gradually subdued on the approach of evening by the attraction which follows the sun. Analogy shows that where the wind creating action is intermittent, the winds resulting from that action should be intermittent also; but this uneven action is often largely overcome where the great prevailing winds create powerful auxiliary forces—in the manner I have shown as affecting the winds in the tropical latitudes.

The air being attracted by the heat of the morning sun over the land from the Rocky Mountains towards the Atlantic, causes in a few days a low atmospheric pressure over portions of the territories lying east of this great mountain range, on account of the obstruction caused by such mountains to the free passage of air-currents from the west. The low barometric pressure thus brought about has the same tendency to move eastward as the surrounding atmosphere, and, at the same time, it attracts the heavier air from the Gulf of Mexico up the Mississippi Valley, and also the cool and heavy atmosphere from the vast northern plains of British America, in order to take the place of the air drawn eastward by the attraction in front of the sun. These areas of low atmospheric pressure, while moving eastward and attracting the heavier air of the surrounding regions, cause a variety of winds, because the air-currents move towards the low pressure region in a circular course, so that a person while facing the wind usually has the area of low barometric pressure on the right hand.* Still the prevailing direction of the great aërial movements is towards the east. And it also appears that during the summer months, because of the heated condition of the great northern plains, the winds from the south more generally prevail to supply the place of the air drawn away from the wide lands lying between the Rocky Mountains and the Atlantic coast; and, during the winter season, the areas of low atmospheric pressure over these lands are more frequently filled from the cold and heavy air of the northern plains. Thus the return winds which

* The common pressure of the atmosphere which surrounds an area of low atmospheric pressure is never entirely equal; on this account the heaviest portion of the surrounding atmosphere will move with the greatest force towards the low pressure area, consequently in the high northern latitudes the air on the northern side of the low pressure area being generally colder and heavier than other surrounding air, it moves with greater force to restore the equilibrum. As the general movement of the area of low atmospheric pressure is towards the east, therefore the heavy air from the north rushes down its western side with a force sufficient to govern the movements of all other surrounding air-currents, according to the general law of circular motion which governs the passage of one mass of fluid through another.

extend eastward across the Atlantic are caused by the a
traction in front of the sun, and also by the displacement c
air caused by the north-east trade-winds on the easter
tropical Atlantic—as I have before shown.

But in addition to the causes above named, for the promc
tion of westerly winds, the warm waters of the Gulf Strean
being spread over a large area of the high latitudes of th
North Atlantic, and thus raising the temperature of the ai
over its waters, is probably one cause of the strong north
west gales which are so prevalent in the United States an
Canada, as well as on the North Atlantic during the winte
and late fall months.

The cold heavy air of the great northern plains of Britis
America would naturally move with greater velocity in th
cold months towards an ocean of warm water, than durin
the summer, because of the greater difference of temperatur
between the land and the sea during winter. The strong
winter gales thus caused have been known to move the ai
over the summit of Mount Washington at a rate exceedin
1500 miles in twenty-four hours. For it will be seen, tha
the several agents which have been pointed out as actin
on the atmosphere of the high latitudes not only cause th
westerly winds, but also frequent storms to sweep over th
high latitudes of the North Atlantic. Yet while the westerl
gales are in force, the atmosphere between them and th
trade-winds of the tropics is comparatively undisturbed, lik
the waters of the Sargasso Sea over which it rests. Thu
it appears that the attraction which follows the sun an
causes the easterly tropical winds, and the attraction in fron
of the sun, which so greatly assist the westerly return wind
of the temperate zone, are separated through mid ocean b
a comparatively tranquil sea, where the surrounding inequal
ities of atmospheric pressure are generally nearly equal, an
act in opposition to each other.

The low barometric pressure usually found on the ocea
in the vicinity of Iceland, is probably caused by the attractio
in front of the sun, in combination with the heated lands o
Europe, and also because the high mountain ranges o

Greenland intercept the free passage of air from the west. Therefore, on account of this mountain barrier, and the general draft on the atmosphere over the seas around Iceland, a low barometric pressure is produced. The westerly air-currents of this region being thus more or less held in check, consequently the westerly winds crossing the ocean further southward are attracted towards northern Europe. But this attractien of the south-western air-currents could not be maintained to any great extent were not the British Isles an area of condensation for the Atlantic vapors wafted over them. The heat set free through this means is sufficient to cause the south-west winds to largely prevail; and it is also on account of these winds the warm waters of the Gulf Stream are forced so far northward as to raise the temperature of the seas and lands of Great Britain many degrees. Therefore, it appears that these south-west winds carry sufficient heat with them through the Gulf waters, and also in the form of vapor, to cause them to be more or less self-sustaining.

The westerly wind-belt of the North Atlantic being mostly destitute of islands, the atmospheric disturbances over its larger portion cannot be recorded in time to be of much benefit to navigators. Still a knowledge of the atmospheric disturbances moving over the islands along its borders may predict with considerable certainty great disturbances over other parts of these waters.

The great rainy calm region abreast the western shores of equatorial Africa is caused by the heated lands which warm and rarefy the atmosphere lying over them, thus attracting the cooler air of the adjacent seas; this attraction, combined with that in front of the sun, is sufficient to overcome the attraction which follows the sun; consequently the great prevailing easterly wind which sweeps over the greater portion of the torrid zone is interrupted,—the equatorial calm region, having a breadth at times of four hundred miles near Africa, which gradually decreases in breadth towards the west until it terminates 1000 miles from Africa. Yet according to the generally accepted theory it should extend

around the globe. Still it is true that this remarkable regi of rarefied atmosphere attracts the cooler air of the north a south, and causes extensive air-currents to move over the s along the coasts of both northern and southern Africa, a also light air-currents from the westward. The air of the ocean winds on meeting, being rarefied, is in a fit conditi to ascend into the upper atmosphere; during which proc the collected vapors are condensed, causing heavy rains, ar at the same time, the heat thus liberated from the condensi vapors causes a still greater rarefaction of the air over t rainy region, and so causing it to become a constant cen of attraction for the lower atmosphere of the surrounding se Consequently, the immense volumes of air thus attracted, meeting, being highly rarefied, are forced to great heigh where, in order to gain an equilibrium, they necessarily cau a lateral pressure above the lower stratum of the atmosphe while the air thus forced away and grown heavy throu cooling naturally sinks over the region from which it was first attracted. Consequently, the regions of descending are able to maintain their usually high atmospheric pressu and still constantly furnish air for the calm rainy region.*

The reason why this rainy area extends so far westwa from the African coast is because the winds which blow shore, although attracted towards the west by the attracti which follows the sun, are also more or less influenced by t rarefied air of the rainy region, and, in consequence, are turn somewhat toward its central latitude; the vapors thus broug together cause a line of precipitation, which gradually lesse as it extends west until entirely lost. The South Atlant furnishes the greater portion of the vapors for the calm rai region against equatorial Africa, on account of its win sweeping over a greater extent of water than the winds fro the North Atlantic side; in fact the air-currents which mo down the coast of Sahara from the northward towards t

* Muhry, writing on this subject, says that the upper air-currents shou move exactly parallel to the surface winds; because the surface win drawn towards the heated calm regions in the torrid zone would natural attract the upper air back to the place from which it was at first drawn.

rainy region are mingled with the dry desert winds to such a degree that the atmosphere for hundreds of miles off-shore is hazy with the dust from the great desert, while the tropical winds of the South Atlantic blow from the wide seas south and east of St. Helena. On account of the shores of tropical Africa extending west to the central longitudes of the South Atlantic, the ocean winds are attracted from the south towards the heated coasts with great regularity. Yet these winds which blow from the seas south and east of St. Helena towards the rainy region are spread out as they move northward, their eastern portion being attracted eastward by the heated shores of Guinea, which combine with the attraction in front of the sun; while the western portion of these trade-winds are attracted towards the west by the attraction which follows the sun, which combines with the rarefied air over the heated lands of Brazil. Yet the middle portion of the great air-current is attracted to the great rainy region abreast Liberia. But the south-east trade-winds do not always enter the rainy region on a direct course, for after passing the equator they frequently form a south-west wind on entering the rainy region. There does not appear to be any necessity for supposing that the rotation of the earth leaves such of the winds behind as turn westward towards Brazil, for if such is the case, why does rotation wholly fail to govern the winds which turn towards the east abreast the coast of Guinea? The fact is, diurnal rotation has nothing more to do with the former wind than with the latter. But the attraction following the sun combined with the heated lands of South America are able to attract the greater portion of the South Atlantic tropical winds towards the west, and this is the direction they generally move over the great Amazon Valley, while wafting vapor sufficient to furnish rain for that extensive region. But the trade-winds of the south-western tropical Atlantic seldom reach the equator, being attracted more or less, according to the season, towards the south-west over the heated plains of Rio de La Plata.

The trade-winds of the South Atlantic generally lose strength after passing northward of St. Helena, for the reason

that the winds are forced to spread over a wider field as they are drawn towards the rainy region; being attracted, as we have shown, on the one hand towards the east, and on the other towards the west, while the central portion moves towards the rainy calm region.

The great Pacific Ocean affords a better field to illustrate the normal movements of the air-currents of the globe than the Atlantic, because of the greater extent of its waters; the great prevailing winds which sweep over it being therefore less influenced by heated continents. But its eastern equatorial region like the eastern tropical Atlantic is subject to calms and rainy weather. This rainy sea lies against the shores of Central America, with winds blowing towards it from the northward and southward, and also light air-currents from the westward; these latter winds being caused by the attraction in front of the sun, combined with the heated and rarefied air of Central America. The immense vapors thus wafted to this region, and also vapors received from the tropical Atlantic, are borne aloft in the rarefied air and condensed. Thus it appears the air of this rainy region is not only warmed and rarefied by the heat of tropical lands and seas, but also from heat set free from the condensing vapors. Under such conditions it is carried into the upper atmosphere, where it cools and flows away in upper air-currents to the latitudes from which it was at first attracted. In fact this seems to be the only way possible to account for the air of surface winds which move in every direction towards this rainy calm region.

This rainy area moving north and south within the tropics according to the sun's declination, is never separated from the continent, and seldom extends westward one fourth of the distance across the Pacific; therefore the winds which blow from the northward along the coast of California, and from the southward along the coast of Peru, do not all meet within its bounds, but are attracted westward by the daily passage of the sun over the sea, and by the heat carried in vapors by preceding winds and set free through condensation on the western shores of the Pacific, and also by the higher

temperature of the western Pacific waters. These great easterly winds thus following the several attractions caused by the daily passage of the sun over the ocean, are turned aside in places, both to and from the equator, through the attraction caused by the heated atmosphere over groups of islands, where they often shed a portion of their moisture. But when the air-currents reach the western side of the ocean they generally unite with monsoons, being attracted by the heated lands of Asia and Australia, and also by the low barometric pressure which often prevails in the higher latitudes of these lands, because of the attraction in front of the sun; which operates in the same manner that I have previously shown prevails on the great plains of North America. Still, such of the vapor-laden tropical winds as are not attracted away from the torrid zone, after crossing the ocean waft their vapors over such East India lands as lie the most directly under the sun, where they are condensed. This region then becomes a centre of aërial attraction for the surrounding seas, causing monsoons, which change their direction across the tropical latitudes according to the sun's declination, thus bringing about the wet and dry seasons of these regions. In fact similar conditions cause the wet and dry seasons of all extensive tropical lands situated to the west of oceans. On the rainy areas thus created the same meteorological performances are carried on, as previously represented in the rainy tropical regions against Central America and equatorial Africa.

That portion of the easterly tropical surface-winds of the Pacific which turns away from the torrid zone, on or near its western shores, generally, on gaining the high latitudes, assumes a counter movement towards the east. This counter movement is probably acquired in part, because the high mountain ranges of tropical America bar the passage of surface winds from the eastward; therefore the cool air of the high latitudes is attracted down the coasts of North and South America, not only to furnish vapor for the rainy region against Central America, but these winds are the source of the great easterly winds which extend across the tropical Pacific Ocean. Consequently through the great displace-

ment of air in the high latitudes of the eastern Pacific, westerly return winds are created to supply the aërial spaces thus vacated. Thus it appears that the attraction following the sun while causing the easterly winds of the tropics, is also, at the same time, one of the prime movers of the westerly winds of the high latitudes. And these westerly winds are probably strengthened by the attraction in front of the sun, which being a concentrated force, holds its power in latitudes remote from the equator. Furthermore, the westerly winds are strengthened at times like the tropical winds by the heat which they convey in vapor to leeward lands. This heat, set free through condensation on the mountain ranges of Oregon and Patagonia, no doubt gives strength to the westerly air-currents in the high latitudes of the Pacific in both hemispheres. In this way, the attraction in front of the sun creates auxiliary forces in the high latitudes, in the same manner that the attraction following the sun creates helping forces in the torrid zone. Moreover, the attraction acting in front of the sun, while drawing the air away from western lands and seas, causes aërial vacancies, consequently the tropical winds are attracted from the east towards the west to fill such vacancies; hence it appears that the great counter-winds of the different zones, although moving long distances in opposite directions over the earth, do really assist each other in their counter movements; which fact goes to prove the economical working of nature in her aërial domain.

On the spaces of ocean which separate the easterly winds of the tropics from the westerly winds of the high latitudes, may usually be observed a high barometric pressure and fine weather. This is because the surrounding atmospheric disturbances are usually antagonistic and nearly equal. Such spaces, having generally no overpowering attraction to govern the atmosphere over them, are still more or less subject to the invasion of the surrounding air-currents which are frequently overspreading their general bounds; and at certain seasons these regions of usually light and varable winds and calms are crossed by furious gales and even hurricanes,

especially on their western portions, where the atmospheric disturbances are somewhat frequent.

On the tropical Indian Ocean the winds are largely prevented from following the direction of the sun's diurnal course, because of the attraction of the heated lands of Southern Asia. Yet on its off-shore waters, south of the equator, the winds pursue a regular course from the east towards the west, wafting vapors sufficient to supply the great lakes at the head-waters of the Nile and Congo. During the period of the monsoons, when the winds are turned alternately according to the seasons from Southern Asia to Southern Africa, the barometric pressure changes with the direction of the wind, the lowest pressure being at the leeward near or at the termination of the periodical wind. These winds pay no regard to the equator as an attracting region, but blow towards regions where the heated atmosphere causes a low atmospheric pressure. The upper air-currents of the monsoon regions have been found to move counter to the surface winds, having been carried aloft at the rainy terminal of the monsoon. For we are told that the monsoons which blow over Java have upper air-currents, which move the smoke and vapors of lofty volcanoes counter to the direction of the surface winds. Which fact seems to prove that the upper air-currents are a continuation of the surface winds that have been raised aloft and deprived of their moisture at the rainy terminal of the monsoon, and are thus seeking an equilibrium by returning to the places from which they were at first attracted. But it cannot be said that monsoons form at their terminals calm-belts of precipitation; for they end in more limited places even than the rainy tropical regions situated to the west of continents.

The southern monsoons which waft their vapors from the equator towards the heated shores of the Arabian Sea, on reaching such latitudes are turned by the attraction in front of the sun, which combines with the attraction of the heated shores of India to draw them towards the Ghaut range of mountains, where their vapors are mostly condensed and precipitated. But the next tropical rainy region to the

westward is nearly three thousand miles distant, where the vapors are borne by the winds from the Indian Ocean together over the great lake region of Central Africa. Therefore, the rainy regions of the tropics are far too broken and widely separated to represent a continuous rainy belt, as declared in the generally accepted theory. In fact, all such rainy terminals of the winds of the torrid zone united would not reach one third of the distance around the earth.

The rainy areas at the terminal of monsoons, as well as those to the west of continents, on account of their low atmospheric pressure are known to attract the lower stratum of the surrounding air; and the air thus attracted is constantly carried aloft over such stormy places, and then moved in upper air-currents to regions of fine weather. Therefore, such performances must be a general law to all large areas of precipitation in all latitudes; even such as the cyclones of the tropics or the more moderate storms of the higher latitudes. The rainy storms, which generally move in an easterly direction over the lands and oceans of the high latitudes, are known to attract the surface winds towards them, more or less, and it is said that upper air-currents move away from such stormy areas towards regions of fair weather. Therefore, the atmospheric movements which occur in the transient rain storms in the temperate zones, are similar to those which are carried out in the more durable rainy areas of the equatorial regions. But the rainy areas of the latter regions being comparatively stationary, the winds do not move on a circular course towards them, as is the case where rainy storms are carried along in the great wind-belts for thousands of miles. Still, during the northern summer months, when the calm areas to the west of continents reach their northern limits, the so-called south-east trade-winds are seen to turn north at the equator, and so on towards the east while entering the rainy region; in fact, during such seasons these calm areas are surrounded by circular winds which move towards the west on the northern side and towards the east on the southern borders.

Although, as has been shown, the attraction following the

sun in the tropical latitudes is considerably weakened through the counter attraction in its front; still, with the auxiliary attractions created by the attraction following the sun, it is generally able to move the lower atmosphere of the tropical latitudes from east towards the west over the greater part of the torrid zone. Hence, such winds move for long distances under a torrid sun, and, consequently, do not so rapidly exhaust the diurnal heat from which they derive their motion, as would be the case if they were moved by equatorial heat, as explained by Hadley. Therefore, it is because of the attraction which follows the sun that the present temperature of the different zones is preserved; for through it the tropical winds are crossing wide oceans, and thus gaining strength by carrying heat in vapor to be condensed on leeward shores; and also to gain yet further power on their passage over the sea by increasing the temperature of the water as they move westward, thus causing them to be great conservers of heat. The theory that equatorial heat is the main cause of the tropical winds appears, on consideration, unreasonable, because of the rapid consumption of heat which would take place through such a process. For it appears that nearly one half of the weight of the atmosphere of the torrid zone is moved as a surface wind; and should it blow towards the equator all around the earth with a velocity common to tropical air-currents, the time required for solar heat to rarefy and raise into the upper atmosphere such immense masses of air appears too limited. And when we realize the great quantity of heat which would rapidly find its way into space, should all tropical winds meet near the equator around the earth, it appears that the sun does not furnish heat sufficient to sustain the present temperature of the globe with such a heat-consuming aërial circulation. But instead of a calm rainy-belt reaching around the earth with winds blowing towards it from the high latitudes, we find widely separated rainy places, caused by hot tropical lands, and maintained mostly against the western shores of continents. Such regions receive heat in the form of vapor from many directions over the ocean, besides being places of at-

traction for the hot winds of torrid deserts, and other tropical lands; and it is only amid such great accumulations of heat that the rarefaction of air is sufficient to carry out the aërial workings of a great rainy calm region. The average heat received from the sun on a portion of the earth equal to a degree of longitude reaching from the poles to the equator, could not perform such work as is accomplished in the atmosphere within the limits of a degree of longitude in any of the calm rainy regions of the equatorial latitudes. The longitudes constantly narrowing towards the poles cannot receive sufficient heat from the sun for such work. On the contrary, the high latitudes are great consumers of equatorial heat. The great aquatic currents on the western sides of the oceans are continually transporting heat away from the equator into the high latitudes; and, by such means, the equatorial regions are parting with much more heat than they receive from regions outside of the tropics. At the same time, the cold return currents of the ocean constantly meeting near the equator and cooling the waters, prevent a central band of equatorial heat from forming over the greater portion of the torrid zone.

Another important consideration largely prevents equatorial heat from being the chief cause of atmospheric circulation; the fact that the globular form of the earth is not favorable for winds to blow northward or southward across its zones all around its circumference, on account of the widening of the longitudes towards the equator, and their contraction towards the poles. Under such conditions, air moving towards the equator from the high latitudes all around the earth would have to fill a much wider space towards the east and west as it neared the equator; which it could not do without greatly lowering the atmospheric pressure; not only on account of its being more heated as it moved under the sun, but also because of the much wider space it must occupy while moving to lower latitudes. That the air so moving may preserve the even atmospheric pressure so generally existing in the different latitudes, the lower stratum of atmosphere which flows as surface winds would necessarily have to reduce its thick-

ness, and also its velocity, in proportion as it spread out over the wider longitudes of the equatorial regions. But, on the contrary, as far as observation goes, the surface winds of the tropical latitudes really occupy the thinnest stratum where farthest removed from the equator. Thus it appears that owing to the above considerations the globular form of the earth is not favorable for air-currents to move northward or southward across the zones all around the earth. Consequently, winds blowing in such directions are generally limited to regions situated on the eastern and western sides of oceans. Therefore, the great easterly winds of the torrid zone, and the westerly winds of the high latitudes, are probably moved by the uneven atmospheric pressure caused by the diurnal heat of the sun towards the east and west, in the manner I have endeavored to explain.

The theory that equatorial heat is the chief cause of atmospheric circulation, necessarily asserts that bands of high atmospheric pressure exist outside of the tropics extending around the globe, from which air-currents are continually streaming towards the equator on one side, and towards the poles on the other. But these imaginary belts, like the belt of low atmospheric pressure around the equator, do not exist. Yet, on the Pacific Ocean, as on the Atlantic, I find regions of high barometric pressure situated near the tropical zone, and on the eastern portion of their waters, with air-currents flowing from them towards the equator. But such areas do not occupy half of the width of the oceans over which they are located. Consequently, over the middle and western parts of such oceans, the winds do not generally blow from the borders of the tropics towards the equator, as I have before declared. Yet, according to Hadley's theory, all of the easterly surface winds of the tropical zone should meet near the equator and find their way to the high latitudes in upper air-currents. But the numerous observations of late years have shown that a considerable portion of the tropical surface winds turn towards the high latitudes after passing westward of ocean centres, perhaps not always in a continuous course, but in a general way. For it is through this great movement

of the tropical surface winds that vapors are carried to furnish rain for the United States.* China, Japan, Eastern Australia, and the great plains of Rio de La Plata.

And when we consider how the great rivers of these countries are fed by the moist winds which spread out from the tropics on the western sides of oceans, they appear amply sufficient to show the general direction of the winds of the torrid zone which so constantly enter the tropics on the eastern sides of oceans. Still, such portions of the tropical winds as blow from the high latitudes on the eastern sides of oceans and meet in calm rainy places near the equator, do without doubt return in the upper atmosphere in counter currents, as I have shown; and such winds are so far in harmony with Hadley's theory. But there is no evidence to show that such lofty air-currents convey sufficient moisture to supply rain to any country. Yet, when we consider how a large portion of the surface winds which enter the tropics on the eastern sides of oceans, are attracted westward, and become loaded with vapor while moving parallel with the equator, and then are turned towards the high latitudes to carry rain to the great countries above named, it is difficult to see why air so moving is left behind through the diurnal rotation of the earth.

Sir John Herschel says, in his treatise on astronomy: "we have only to call to mind the comparative thinness of the coating which the atmosphere forms around the globe, and the immense mass of the latter compared with the former (which it exceeds at least 100,000,000 times) to appreciate fully the absolute command of any extensive territory of the earth over the atmosphere immediately on it in point of motion."

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* Lieut. Maury, in his elaborate explanations of the atmospheric currents, was led, through Hadley's theory, into the error of supposing that the vapors which produce rain over large countries situated like the United States, were taken from distant oceans in upper air-currents; because the theory he advocated could lead him to no other conclusion. But it is now beginning to be known that there is no land on the face of the earth but what derives a greater part of its rain directly through surface winds. The upper air-currents which proceed from the rarefied air which ascends from the rainy regions, having already parted with the greater portion of their humidity, and because of their thinness and low temperature, are in a poor condition to carry moisture to any country.

Accepting this fact, it does not appear that the air, even when moving towards the equator, could be left behind sufficiently to create a north-east or south-east wind, much less an east wind which does not move at all towards the equator; neither could air-currents moving towards the poles so outstrip the speed of the earth's rotation in the high latitudes as to create westerly winds; especially, winds moving from the polar side of west. Moreover, as has been pointed out, the solar heat which warms the seas of the torrid zone cannot create a marked band of equatorial heat around the earth on account of the cool ocean waters constantly moving from the north and south and meeting near the equator. Furthermore, if equatorial heat was the prime mover of the atmospheric currents, it would be impossible for solar heat to maintain the present temperature of the globe, because of the rapid consumption of heat which would take place under such conditions.

The test to be applied to every theory is its success in accounting for the facts which it was framed to explain. Yet, after a long acceptance of Hadley's theory for explaining the cause of the great prevailing winds, dissatisfaction is frequently expressed, by persons who study the subject, at our imperfect insight into phenomena so varying and contradictory, and that we look in vain for a direct manifestation of these laws which govern meteorological phenomena. This frequent failure to harmonize the generally accepted theory with the actual movements of the great air-currents over the earth, is probably because the said theory is only true so far as it is in harmony with the actual operations of nature.

Having explained the manner in which the great prevailing winds are produced, and having also pointed out, to some extent, how such winds in their sweep across oceans affect the temperature of the sea, I will endeavor to show also how the prevailing winds are the main cause of ocean currents. For among the vast operations of nature the circulation of the waters of the sea is of great importance, because through its action the temperature of the different zones is largely governed.

It is well known that the ocean waters of the tropical latitudes move in large streams which send their strong currents far into the more northern and southern seas, thereby raising the temperature of the ocean waters of the higher latitudes, while the cold waters of the polar seas send returning currents to cool the waters of the torrid zone.

To account for the manner in which nature works to perform this great task, has been the cause of much speculation. Early writers on the subject supposed that the great prevailing winds of the tropics were the principal cause of such ocean currents as were then known. But their knowledge of the winds and currents of the sea being necessarily limited, they failed to confirm their views. The attention of the public was subsequently directed to the theories of ingenious persons who even insisted that wind had little to do with the general circulation of the waters of the sea, and that without wind there would be a perpetual and uniform system of tropical and polar currents, owing to a difference of density in the ocean waters, caused by a difference of temperature and saltness in the waters of the high and low latitudes; and also through disturbance caused by the rotary motion of the earth in connection with the above named influences.

The diurnal rotation of the earth in combination with great prevailing winds is now regarded by persons of high authority on such matters as the main cause of ocean currents. But, while accepting such theories, they have neglected to notice the full effect caused by great air-currents sweeping over oceans partly bounded by land. For when we consider their full potency, we find a simple and ample explanation for all of the great surface currents of the sea; and through them we also find an explanation for the great climatic changes which, during long intervals of time, have passed over the high latitudes of the earth.

The waters of the North Atlantic offer a good field to illustrate these statements. The trade-winds which sweep over their tropical portion, while serving to supply the western slope of North America with rain, are at the same

time, with the assistance of strong westerly winds sweeping across their northern latitudes, forcing the waters of tropical seas through favorable channels far into the northern seas, thereby warming lands which without such life-giving assistance would remain cold and dreary regions. We see nature thus operating where tropical heat finds its way to high northern latitudes through that wonderful ocean current, the Gulf Stream.

Among the numerous and conflicting opinions that have been conceived concerning the cause of this great ocean stream, the theory advanced by Dr. Franklin, a few years after being informed of its existence by that observing old whaleman, Capt. Folger, has long been considered by intelligent seamen as the most probable. Franklin, in his explanations of the Gulf Stream current, declared that it was occasioned by the constant trade-winds blowing the surface waters of the tropical Atlantic into the Caribbean Sea and Gulf of Mexico, thereby raising their waters above the common level of the North Atlantic. And this is evidently one of the principal causes of its existence; but not the only cause. For the raised waters, without an easy channel to a lower sea level, would naturally return to the seas from which they were at first blown, through under currents, when the heaped pressure became sufficient to cause them. But nature, in order to facilitate the Gulf Stream current, has, in addition to the trade-winds, made use of the great sweeping force of the westerly winds of the temperate zone, which have the same effect on the waters of the North Atlantic as all other winds that blow over the water, that is, to blow its surface waters from the windward over to the leeward. Therefore, these prevailing winds sweeping over the yielding seas blow the surface waters of the Atlantic away from the American shores, and thus create a low sea-level along the coast, extending from Cape Hatteras to Greenland, the waters abreast of Newfoundland occupying the central portion of this wide depression. Consequently, the raised waters of the Gulf of Mexico find an easy outlet to this low sea-level through the deep passage around Florida. The

tropical waters, being warmer than the northern seas, do not readily mingle with them, but float over them; moreover, the vast streams of water on their northern passage are not arrested on the low sea-level, but retain through their force of motion somewhat of their northern course while being gradually turned by opposing currents and prevailing westerly gales towards Europe, where they serve to warm the atmosphere of that portion of the globe. Yet, through their force of motion northward, combined with favoring winds on the North Eastern Atlantic, a portion of the waters are able to pass to the north of Europe, and mingle with the Arctic seas. Meanwhile, this great flow of tropical waters northward receives considerable additions to its volume after passing the Florida seas, from the general high sea-level of the tropical Western Atlantic.

But the Gulf Stream is not the only current that is moving towards the extensive hollow caused by prevailing westerly winds along the North American coast; for it receives a great current from the Arctic seas which moves down upon it from Davis Strait and the west coast of Greenland, heavily freighted with ice to help fill its wide depression. This great arctic current is caused by the surface waters of the North Atlantic being swept eastward by strong westerly gales, through the wide seas between Iceland and Great Britain, into the Arctic Ocean, causing a high sea-level on the seas north of Europe and Asia. The narrow channel of Behring Strait, opening on a high level in the Pacific, only increases their elevation; while Davis Strait, opening directly on the low sea-level of the North Western Atlantic, forms a convenient outlet for the raised waters of the arctic seas; in the same manner the straits of Florida form the outlet to the raised waters of the Gulf of Mexico.

While considering the ability of the prevailing westerly winds to do the work here ascribed to them, it is well to notice their great transferring power in the huge waves which they constantly throw on the Atlantic shores of Europe, whose driving force on the west coast of Scotland ranges from six hundred to six thousand pounds to a square

foot. In tracing the whole round of the Gulf Stream, and Arctic currents, it will be seen that the westerly winds, by driving the surface-waters of the Atlantic eastward, thus create a high sea-level against the coast of Europe; it is only such waters as pass to the north of the British Isles that are forced into the Arctic Ocean; while the heaped waters south of Ireland naturally return to the depressed seas caused by the trade-winds along the African coast, to be blown again into the Gulf of Mexico.

Thus two great ocean currents are caused by strong prevailing winds: one embraces the Sargasso Sea and the large islands of the West Indies, while the other moves around Iceland, Greenland and the North Pole. This latter current, which finds its way from the high sea-level north of Europe and Asia, through the various seas and channels of the Arctic Ocean, to the low sea-level along the American coast, is constantly kept in motion by the ample force of strong westerly gales which sweep across the North Atlantic, a distance of three thousand miles, causing, as I have shown, a low sea-level along the North American coast, and a high sea-level on the seas north of Europe and Asia; which proves sufficient to cause return currents through the various channels of the arctic seas. These return currents, while moving from the high ocean level, are probably more or less influenced in their movements by the changing winds of the Arctic Ocean. Still, we find the arctic currents returning regularly through the several channels leading into Davis Strait. This portion of the returning waters explorers have found to continue east from the high ocean level along the northern shores of Asia, and so onward in a north-easterly course towards the various channels leading to Baffin's Bay. This is the general direction of the currents as reported by whalemen cruising north of Behring Strait. But the arctic waters further north, being more removed from the influence of westerly winds, return along the icy channels of Spitzbergen and so north of Iceland down the east coast of Greenland, to gain the low ocean level on the American side of the Atlantic. This westerly return current appears to

great currents of the sea through their wide sweeping force, we should notice their constant transporting of water in vapor as adding considerable power to air-currents for producing inequalities of level on the surface of the ocean. The winds which push the surface waters of the sea away from continents causing depressed sea-levels, are from the land; therefore, they are dry winds, and in a condition to cause a rapid evaporation. The winds are found to operate in this way, where the dry winds on the African side of the tropical North Atlantic maintain a rapid evaporation which gradually decreases in their sweep across the ocean; consequently, when they reach the West India Seas and the water sheds surrounding them, the precipitation is probably much greater than the evaporation. Still, this minor tendency of the wind for circulating the ocean waters mostly acts in unison with its sweeping force. Yet, when we consider the great amount of water evaporated from tropical seas which is borne by the winds to the high latitudes, we can realize the source of the great glaciers which are constantly forming in the polar regions. Moreover, the water thus taken from the low latitudes, combined with the great amount of tropical water forced towards the poles by prevailing winds, in the manner in which I have shown how the Gulf Stream is carried northward, causes in many parts of the sea a slow under-current to set from the high latitudes towards the equator.

Writers have endeavored to explain the cause of such ocean-currents through the effect produced by a difference of density in the waters of the sea, in consequence of their difference in temperature, and also through their difference of saltness which is said to exist between the poles and equator; but it is now estimated that such differences are nearly equal and quite antagonistic.

The diurnal rotation of the earth, so often declared to influence the direction of winds and ocean currents, fails to show its power over the movements of the ocean waters in places of extraordinary facility for such an exhibition. To confirm this statement, attention is called to that portion of the equatorial current which turns south from the great high sea-

level of the tropical South Atlantic abreast Cape St. Roque. This current, according to the diurnal rotation theory, should be turned off towards the east while moving southward; but instead of doing so, it continues on a southerly course along the South American coast direct for a low level of the ocean against Patagonia. This depression is caused by the westerly winds blowing the Atlantic waters away from the eastern coasts of South America. Consequently, the ocean waters perform a journey of over twenty-five hundred miles in direct opposition to the diurnal rotation theory, in order to gain a low portion of the ocean, which is lowered sufficiently by prevailing winds to attract the antarctic waters from the south beyond Cape Horn, as well as the equatorial waters from the north. These northern and southern currents meeting on the low ocean level against Patagonia are turned towards the east by the strong westerly winds of the high southern latitudes. The Mozambique current is another refutation of the theory which declares that ocean currents running north or south are affected by the diurnal rotation of the earth. This vast movement of tropical water along the eastern coast of Africa towards the southern ocean, is caused by the prevailing easterly winds which sweep the waters of the tropical Indian Ocean against the African shores, which causes a current to set southward through the Mozambique channel; but after passing Madagascar this current does not turn towards the east until forced in that direction by the strong westerly winds of the southern ocean. On the contrary, this current follows the African coast in a south-westerly direction; and at times even passing around the Cape of Good Hope when the winds permit, to gain a low sea-level caused by the south-east trade-winds on the South Atlantic, abreast South-western Africa. In fact but a small portion of the ocean-currents can be explained by virtue of the earth's axial rotation as now set forth in our text-books, while the effect produced by winds blowing over the sea everywhere proves them to be the main cause of ocean-currents. While considering the ocean-currents, I will call attention to the North Pacific waters, which appear to have little to do with.

the circulation of the arctic seas because of the nearly uniform level of the two oceans at Behring Strait. Moreover the circulation of the Pacific waters affords no perfect comparison to the currents of the North Atlantic, owing to geographical differences; yet, they are produced by the same natural agents. But on account of there being no continuous land barrier extending across the East India Seas from Asia to Australia, the Japanese current has no land-locked sea to give it head; consequently, it is less concentrated it its movements than the Gulf Stream. The East India Seas having numerous channels opening on the low sea-level of the Indian Ocean, a portion of their heaped waters created by the prevailing easterly winds of the tropical Pacific are drawn in that direction, instead of their wide volume being attracted to the depressed seas, caused by the westerly winds which blow over the Japan waters. Thus it happens that the great circular North Pacific current, although enormous in its movement, is greatly weakened in its course. Hence, it will be seen that the prevailing winds of the Pacific operate in the same manner on the ocean waters as the Atlantic winds; but from the lack of a continuous land barrier extending from south-eastern Asia to northern Australia to turn away the whole volume of the great Pacific equatorial currents into the more northern and southern latitudes, the seas in the high latitudes of this ocean are deprived of a large portion of their tropical warmth. For this reason, the seas north of Japan, owing also to extensive land obstructions, are not largely penetrated by the tropical currents; and even on the shores of Alaska it is said that glaciers reach the tide-water.

To show the universal action of the wind in connection with the land on the waters of the earth, brief notice will be called to all of the principal high and low sea-levels caused by such action, including those which have been pointed out. The prevailing westerly winds of the northern temperate zone, as has been shown, produce a depressed sea-level along the eastern shores of Asia, and along the eastern shores of North America; consequently, we find a high sea-level against extensive lands under their lee, such as are maintained

against the Atlantic shores of Europe and the Pacific shores of North America north of Mexico. In the torrid zone, we find the prevailing easterly winds creating depressed sea-levels on the Atlantic, along the western coasts of northern and southern Africa; and their opposite high sea-levels on the lee shores of tropical South America and Mexico. On the tropical Indian Ocean we find a depressed sea to the westward of northern Australia, and a high sea-level on the African side of the ocean, which sends an immense current to the south—its main point of escape to the general level of the southern ocean. On the tropical Pacific we find a low sea-level abreast of Peru and Mexico, and a vast high sea-level on the leeward side of the ocean against the East India Islands. This great high ocean level sends off its heaped waters to the south along the eastern shores of Australia, and to the west through Torres Strait and other India passages, to the low sea-level of the Indian Ocean; and a northern current to the depressed seas abreast of Japan. The great belt of westerly winds sweeping the southern seas produces comparatively few inequalities on the ocean's surface from the lack of obstructing lands. Yet we find, where the southern lands of south America partly cross this great wind-belt, there is maintained a high sea-level against the Pacific coasts and a low sea-level along the Atlantic shores. Other lands penetrating this zone of westerly winds, lack extent, or are too broken for the winds to cause great and constant inequalities on the ocean's surface. But its single, great, high sea-level against the Pacific shores of Chili extending to Cape Horn, sends a vast cold current upon the depressed seas against Peru. This mighty rush of cold water from the high level of the southern ocean upon the great low level of the tropical Pacific lowers the temperature of the latter sea many degrees, so that the Galapogos Islands, at the equator, have a colder sea than other tropical islands. In fact, the temperature of all tropical oceans is largely governed by the amount of cold waters forced into them from the southern ocean. Aside from the slow movement of cold water in under-currents towards the equator, we find that the

low sea-level on the South Atlantic west of southern Africa, caused by the south-east trade-winds, attracts cold surface water from the common level of the southern ocean; and it also attracts a portion of the warm waters of the Mozambique current, or, as it is usually called, the Agulhas current, where it passes around southern Africa into the Atlantic. Through this cause, the waters of the tropical Atlantic are not cooled so extensively as the Pacific waters are cooled by the Peruvian current. And it is because of this warm water running from the Indian Ocean into the Atlantic, that the comparatively limited tropical waters of the latter ocean are able to maintain their present high temperature.

The great high and low sea-levels of the Indian Ocean are more governed by the changing monsoons than the waters of other oceans; still, on its wide tropical seas, south of the equator, is found a constant easterly wind, causing a low sea-level on its eastern side which attracts the cooler waters from the south along the west coast of Australia, and also the warm waters from the high level of the tropical Pacific through Torres Strait and other East India channels. Consequently, the cold current which sets northward against western Australia has less effect for cooling the tropical Indian waters than it otherwise would; therefore, the tropical waters of the Indian Ocean have a higher temperature than other tropical seas.

The direct flow of a large portion of the tropical Pacific waters to the low sea-level of the tropical Indian Ocean through the East India channels, causes the equatorial currents of the Pacific to be generally much stronger than the equatorial currents of other oceans.

From this brief explanation, it will be seen that the great high and low sea-levels of the globe are caused and governed by the position of continents and the force of prevailing winds blowing to and from them over the sea. For when the winds blow the surface waters of the ocean away from a continent, the depression thus caused affords a high sea-level against an opposite shore. Therefore, in connection with land barriers, the great counter wind-belts of the globe are

constantly causing unevenness on the ocean's surface sufficient to mingle the waters of the different zones; and it is through this means the tropical waters are able to enter the high latitudes, and thus raise the temperature of regions which otherwise would remain intensely cold. Still, writers on this subject have always neglected to state how this important fact is accomplished. They never explain how the Gulf Stream is attracted northward along the American coast from Florida to Newfoundland, because of a low ocean-level; which is caused through the westerly winds blowing the surface waters of the Atlantic eastward from a continuous shore. For it is only through this means that the tropical waters of the West India seas are enabled to reach high northern latitudes. And while the warm waters are being drawn to this low sea-level, the westerly winds are drifting them eastward and covering the North Atlantic with their warmth, and, consequently, raising the temperature of extensive northern regions. Therefore, were the raised waters of the Gulf of Mexico not thus attracted to northern seas, they would return to the low sea-level abreast the African coast from which they were at first blown by the trade-winds without entering the cold northern latitudes, and thus deprive Europe of its mild climate. Hence, the temperate climate of Europe depending entirely on the warm waters of the Gulf Stream entering the high latitudes through the regularity and force of winds, any unusual change in the strength and direction of such winds must cause a corresponding change of climate in the regions under their influence. In this way, we account for the exceptional cold winters which have occurred in Europe during many centuries. For when the winter gales blow with usual force and persistence from the northward and drive the gulf waters largely away from the seas of the high northern latitudes, the temperature of Europe and Asia and other northern regions is naturally lowered in proportion to the heat thus turned away from the northern seas. The great North Pacific currents, like the Gulf Stream, are governed by the winds, while at the same time the movement of these currents largely affects the winter temperature

of a large portion of North America. Consequently, when the winter winds of the North Pacific are favorable for its tropical currents to reach a high latitude, the temperature of North America is somewhat higher than when the winds are unfavorable for the tropical currents to enter its northern seas. But the exceptional cold winters caused in this manner are of little account compared with the great and prolonged climatic changes which have at wide intervals passed over the northern temperate zone. For there appears to be abundant evidence of great ice periods, and intervening eras of mild weather, having been maintained on the now temperate countries of both the eastern and western continents. The stony record on lands lying above the latitude of 40°, in both the northern and southern hemispheres, everywhere assures us that from the earliest times of which geologists can take cognizance, down to the present, our earth has experienced many changes of climate.

The greater portion of North America above the latitude of 39°, north to the shores of the Arctic Ocean, has been furrowed and scoured by the action of ice. Vast traces of ancient glaciers are also found in Europe. For it is reported that ice sheets have left unmistakable marks of having overrun the greater part of the lands lying between the arctic seas and the latitude of the Pyrenees. In Asia, evidences of glacial action have been noticed from northern Siberia to the mountains of Syria.

The great glaciers of the Himalaya have in times past attained gigantic proportions. In Northern China, huge boulders are found scattered over the valleys and at considerable distances from the mountains. In fact, the geological records of our country alone are sufficient to prove the intense cold which at one time existed in the temperate regions of the northern hemisphere. The southern hemisphere in proportion to the extent of its land shows ample traces of former ice action. From the latitude of 40° to the southern extremity of the American continent there is said to be the clearest evidence of former glacial action, in numerous boulders scattered over the land. On the Pacific shores, from the

Island of Chiloe to Cape Horn, the coast is fringed with deep fiords, which appear to have been channeled out by ice like the fiords of Norway and Greenland, and late investigations have shown that in New Zealand colossal glaciers at one time descended to the low lands of that island, and even traces of glacial action have been observed in South-eastern Australia, and also in the Province of Natal, South Africa. Kerguelen Land is pierced with deep narrow fiords which have the appearance of having been scoured out by ancient glaciers. The lands of the antarctic circle to-day are supposed to be covered by an ice-sheet, of which the great ice barrier surrounding them affords ample proof.

But while we possess sufficient proof of a frigid climate having, at different periods, extended down to the low latitudes of the temperate zones, explorers also find, on the shores of the Arctic Ocean, the fossil remains of delicate corals and mollusks, which could only exist in seas possessing a warm temperature. The fact of coal being found in frigid lands shows that the vegetation of the coal measures once flourished in what is now the frozen zone. Dr. Hayes found on the shores of Grinnell Land certain fossils, the nature of which shows that, at some distant date, a warm ocean capable of nourishing corals and chambered shells must have submerged that region.

The changes of climate which are thus shown to have taken place in the high latitudes have been the occasion of many theories for explaining the conditions which may have caused them. Yet, such explanations do not appear to harmonize with the common operations of nature sufficiently to be accepted by many persons who have given the subject considerable study. My impression is, that when the conditions are favorable for the warm waters of the tropics to reach the polar seas, the climate of arctic lands will be raised in proportion to the heat carried by such warm waters to their shores. On the other hand, when the conditions are such that the warm tropical currents are forced away from the high latitudes, it will result in a cold climate, because the heat received in such latitudes from other sources would not

be sufficient to prevent it. I also contend that the only way by which tropical waters are moved into the high latitudes sufficient to affect their climate to any great degree, is through the force of great prevailing winds, which are constantly sweeping over the ocean in opposite directions in the different zones, and thus creating great high and low sea-levels abreast the shores of continents, and so causing the waters of a high sea-level to move through the action of gravitation to the regions of a lower ocean-level, in the manner I have explained in the preceding pages, and shall further explain in the following pages.

During the years in which the Atlantic Ocean has been confined to its present limits, and therefore possessing the same resources for acquiring heat as now, it appears that the temperature of extensive northern lands has been slowly lowering. This lowering temperature has probably been brought about through the independent circulation of the arctic seas. The channels which now lead into Davis Strait afford a passage for the waters of the high sea-level which exists to the north of Europe, to the low sea-level abreast Newfoundland; this difference of ocean-levels being created by strong westerly winds which—as I have before explained—blow the surface waters of the Atlantic from the North American coasts over against the shores of Northern Europe. Therefore, a large portion of the waters of the high sea-level thus created, return through the arctic seas and its channels down through Davis Strait, at the same time carrying with them the coldness acquired from their arctic passage. The great amount of cold water thus poured against the Gulf Stream tends to force it away from the American shores and the coast of Greenland, and so largely prevents the warm waters from entering the polar seas; and it is probable that the arctic channels have served, ever since the ice-sheets of the last great northern ice period were melted away, to keep up the independent circulation of the arctic waters, so that there has been a gradual increase of cold in countries situated in high northern latitudes.

The historical evidences of Greenland and Iceland possess-

ing a mild climate seven centuries ago, shows that there has been some cold agent acting on those regions since that time. In fact, the climate of Northern Europe has long been accused of growing colder, and, as far as I know, history gives no account of a country situated in high northern latitudes of having possessed a colder climate than it has been subject to during the last century. It is true, we read of uncommon cold winters which have appeared within the last two thousand years, but they were noted on account of being an exception to the general temperature of the countries where they occurred.

A change of climate, brought about through the independent circulation of the arctic waters, must necessarily be slow, and therefore hardly perceptible to a single generation. The collection of snow and ice on lands situated in high northern latitudes makes it appear that the cold must continue to increase in proportion to the spread of such snow and ice. Greenland to-day is nearly covered with ice-sheets. That country, as well as some other northern lands, is constantly gathering cold in the shape of snow and ice. For there is no doubt but that more snow falls on such lands in winter than is melted during summer. Therefore, the accumulation and spread of snow and ice constantly destroys the power of the sun for heating such lands, because the conditions necessary for receiving and radiating solar heat are being gradually lost on account of the gathering snow. Therefore, from the fact that the heat which finds its way northward from the tropical seas is gradually overcome by the accumulation and spread of snow and ice, and also from the fact that the Gulf Stream is largely forced from the high northern latitudes by the arctic currents, it appears that the cold must be proportionally on the increase, and this slow increase of cold will probably go on; for the deep arctic channels which circulate the arctic cold will be slow to close, because the surface ice acts as a shield to the deep waters beneath. We know the cold of winter does not seem to weaken the polar currents running through them; for they succeed in the winter season with the help of north-west gales in forcing the surface waters

of the Gulf Stream over ten degrees further from Greenland than they do in the late summer months.

The only way of arresting the increase of cold with such an amount of heat as the tropical Atlantic can afford the Gulf Stream at the present time, would be through the slow process of glacial action in the vicinity of the Arctic Straits. For should the glaciers of North America, after accumulating on extensive lands sloping northward, obtain sufficient thickness to give them irresistible motion towards the northern straits, the process of closing them would be comparatively short and effectual. This being completed and the independent circulation of the arctic waters arrested, the high sea-level of the western tropical Atlantic and Gulf of Mexico would be the principal water to seek the low sea-level along the American coast. This warm water meeting with little opposition from polar currents would wash all the shores and harbors of North America from Florida to Greenland. Such flowing of tropical waters northward would probably check the further accumulation of ice on the North Atlantic shores, and also maintain a temperate climate of long continuance over a large portion of Europe. The centre of polar cold, during such a period, would be confined to the great ice-sheet blocking the arctic channels. For the immense glacier closing them would extend southward to the head waters of the great Mackenzie River; and being favorably located to receive and retain the snow created from the vapors of the North Pacific Ocean through a long period, it would, under such conditions, be the most massive sheet of ice that could form on the northern hemisphere. Hence, owing to its cold location and immense extent, it would require a long time to free the arctic channels which now give a partly independent circulation to the northern seas, and, consequently, serve to lower the temperature of a large portion of the seas and lands situated in high northern latitudes. Yet, it is doubtful if the heat of the tropical North Atlantic was ever alone sufficient, or ever can be able to melt away the ice-sheets of a great ice period.

But when we consider more widely the oceanic changes

that must have occurred during the perfection of the greatest ice periods which have taken place in the northern hemisphere, we find other sources of heat added to the Gulf Stream currents which would be sufficient to rapidly melt the most extensive ice-sheets that could form in the northern latitudes. For when the Southern hemisphere became largely free from ice, the earth's centre of attraction would be moved northward at the consummation of a northern ice period; consequently the waters of the southern seas would follow such attraction and raise the general level of the northern oceans, and thus submerge the lower lands of the northern hemisphere.* Under such conditions, the low lying lands of northern Africa would not present the effectual barrier they now maintain against the heated waters of the tropical Indian ocean from entering the North Atlantic. We now see the great equatorial currents of the Pacific Ocean extending through the East India Straits, and joining the equatorial currents of the Indian Ocean, and on reaching the African coast this immense mass of tropical water is turned southward into the Southern Ocean, where only a small portion of the warm waters are able to pass around the Cape of Good Hope into the Atlantic, because the westerly winds turn the currents eastward in the high latitudes. Yet, when we consider that the great Sahara Desert has been in part submerged (which fact has been proved by the marine shells which have been found widely distributed over its surface and embedded in its sands), we can conceive how, during such submergence, the great tropical currents of the Pacific and Indian Oceans, instead of being turned towards the Southern Ocean, would continue on through the Red Sea and unite with the tropical currents of the North Atlantic. For when the low lands of Suez and the low plains of Sahara were submerged, a strong cur-

* Adhemar, who first called attention to the fact that a large accumulation of ice about one of the poles would cause a dislocation of the earth's centre of gravity and a new set of levels for the ocean, has had many to embrace his views, on account of the unmistakable traces of uprisings and submergences of land having taken place in the high latitudes.

rent must have set in through the Red Sea from the high level of the Indian Ocean to the low level of the tropical Atlantic, on account of the low sea-level of the latter ocean, which now lies abreast the Sahara coast, being brought considerably nearer the Suez region than it now is; therefore, the waters of the great high level of the tropical Indian Ocean would find a free passage to the low sea-level of the tropical Atlantic: at first they would pass through the Red Sea and so onward through both the Mediterranean and Sahara waters. But the Mediterranean and Sahara seas, on account of their broad connection with the low ocean-level of the tropical Atlantic, would have their sea-levels largely governed by it, on account of there being no wide surface waters forced into the Mediterranean except the current running through the Red Sea from the high level of the Indian Ocean. Besides this, the North Atlantic being much wider than at this age, the difference in its ocean-levels would be greater than now in the tropical latitudes, on account of the longer sweep of the prevailing winds over its surface. Moreover, after the ice-sheets had partly melted away, the great high and low sea-levels of the eastern North Atlantic would be more separated than now; because its great high level would be maintained over the submerged regions of northern and western Europe, including the areas of the Black and Caspian Seas; therefore, the high lands of southern Europe would intervene between this high ocean-level and the low sea-level over the Sahara. Consequently, the difference in the two ocean-levels would not only be greater than what is maintained to-day, but the low sea-level of Sahara, being debarred from the high ocean-level to the north, would in consequence considerably strengthen the currents which would run into it from the high ocean-level of the Indian Ocean. Travellers have reported that a large portion of the Sahara Desert abreast the Atlantic coast is below the general level of the ocean.* Hence, it will be seen that this wide region,

* The northern part of the Sahara, a thousand miles from the Atlantic, is described by Dr. Lenz (who crossed it in May, 1880,) as a plateau over a thousand feet high, while the valley at the foot of the Atlas is low, as also are the desert lands in the region of the salt beds of Taudeni. Dr. Lenz is reported as frequently describing the Sahara as a sea-bed.

when covered by the sea, was in the direct course of the great equatorial currents. Therefore it appears that when the low lands of Egypt and Sahara were submerged, the North Atlantic must have been the receptacle of a large portion of the conserved heat of the torrid oceans of the globe. The Gulf Stream, thus greatly enlarged and possessing the highest temperature to be attained from tropical seas, would carry ample heat into the high northern latitudes to subdue their frigid climate. And when we consider that the low-lying lands of the northern hemisphere were submerged during the breaking up of its great ice periods, it is evident that at such times the warm gulf waters must have flooded the whole Mississippi valley. And while the vast ice-sheets melted away, the warm waters extended over the great lake region; the wide shallow seas opening even into Hudson's Bay. The winds during such a period prevailing as now, would sweep from the trade-wind region over the Gulf of Mexico and thence over the shallow seas of the Mississippi valley, thus assisting the tropical currents on their way to the low sea-level of the north-western Atlantic, which would be extended to Hudson's Bay. Hence, it appears evident that under such conditions the warm waters of the high sea-level of the Gulf of Mexico would gain a much higher latitude than they now reach; and being supplied with warm water from all of the torrid oceans of the globe, such waters would so raise the temperature of the arctic seas that not only would ice disappear, but in time corals could be nourished in the northern seas. These warm surface waters being blown by the westerly winds towards northern Europe, would not only melt the ice from its lands, but such conditions would give warmth to the wide shallow seas, which during such areas must have covered all the low lands of that extensive region. The marine deposits which are found embedded in the low lands of Europe, attest the warm temperature of the ancient seas. Thus when the geographical conditions of such periods are considered, it appears that the conserved heat of the tropical Pacific and Indian Oceans having direct access to the North Atlantic, the Gulf Stream must have carried sufficient heat

into the high latitudes to subdue the arctic cold however wide its extent.

The waters of the Persian Gulf during periods of great submergence may have extended to the submerged regions of Suez, and thus in addition to the Red Sea formed a channel for the waters of the high level of the Indian Ocean to pass to the low level of the Sahara Sea. But I do not know as the geological structure of that region would support such an opinion. Writers have thought that during ages prior to the later ice periods, the waters of the Persian Gulf extended to the Caspian Sea, so that the warm waters of the Indian Ocean found a free passage to the seas of northern Europe and Asia. But the mountain ranges which now separate the Caspian Sea from the Persian Gulf appear to confute such an assertion. Yet even if such a passage was open it would only connect the high level of the Indian Ocean directly with the high level of the north-eastern Atlantic; therefore there would be little or no current running from one high ocean-level to the other. Consequently, in order for the warm Indian Ocean waters to have ever gained the high level of the seas of northern Europe and Asia, they must have been attracted first to the low Atlantic level over the submerged lands of Sahara, and thence forced by tropical winds across the Atlantic into the Gulf of Mexico, and thence carried northward through the Gulf Stream into the high latitudes, and thence forced by the westerly winds across the Atlantic to the seas north of Europe and Asia. Thus it will be seen that the Indian Ocean waters would have a long and roundabout journey to perform in order to gain the high ocean-level of northern Europe and Asia. Still it would be the only way in which the winds and gravitation could act to compel the Indian Ocean waters to perform such a journey.

The ocean waters attracted into the high latitudes of the northern hemisphere during a northern ice period, probably could not return to the southern hemisphere immediately on the melting of the northern ice-sheets, on account of the great quantity of ocean water being constantly forced north-

ward from the Indian Ocean through the seas of Northern Africa. Thus it will be seen that the conditions would be favorable for the prevailing winds and currents to hold the ocean waters north until the antarctic ice attained weight sufficient to attract the waters southward. Therefore, the submergence of the low northern lands must have continued for a considerable length of time after the ice had melted away from the northern regions; and during such eras, the high sea-level of the North-Eastern Atlantic was maintained by the westerly winds on the shallow waters which covered all the low lands of Northern and Western Europe. Although this vast high sea level of warm water found a limited outlet through the straits now leading out of the Black Sea, yet the high sea level was maintained so far eastward against Siberia, it is probable that a strong current ran out of Behring Strait to the low levels of the North Pacific, whence the surface waters were driven along the tropical zone by the prevailing winds into the Indian Ocean, thence through the Sahara Seas into the North Atlantic, and so onward by the Gulf Stream returning again to the Arctic Seas. In this vast movement of the surface waters of the Ocean around Europe and Asia, it will be seen that over two-thirds of the distance was performed under the tropical winds; in fact only a small portion of the great circular current passed through the Arctic seas, whose waters under such conditions would attain a comparatively high temperature.

I have stated how the lands of the high latitudes of the Southern hemisphere present the same geological traces of great climatic changes as the lands of the high Northern latitudes. The islands and shores of Patagonia and New Zealand show ample traces of ancient glaciers. Kerguelen Land shows traces of having passed through great changes of climate; at this date, it is too cold to support even a shrub, yet abundant fossil remains prove that a portion of its lands were once covered with forests; which serves to show that its shores have been washed by the tropical waters of the Atlantic and Indian Oceans. This land also has the appearance of having passed a period of far lower temperature

than it now possesses, although its cold climate now makes it a land of desolation. Yet these climatic changes have probably been produced by the slow and constant operations of nature now in force.

The lands of the antarctic circle, now heavily capped with ice, will probably long remain loaded with glaciers, because of the independent circulation of the surface waters of the Southern Ocean. For so long as such conditions exist, the climate of high southern latitudes must be gradually growing colder. To accomplish this work the westerly winds are constantly blowing the surface waters of the southern seas from west to east around the globe. Therefore, the surface waters of tropical oceans blown against continents by the prevailing easterly winds of the tropics, find no attractive low sea level in the southern westerly wind belt sufficient to draw them far into the southern seas.

It is generally known to navigators that the great surface currents of the southern ocean, between the latitudes of 40° and 60°, form an effectual barrier, or "cold wall," to the further progress southward of the equatorial surface currents. Consequently, owing to the exclusion of the tropical waters from the high southern latitudes, the antarctic ice-cap is constantly increasing its dimensions. And this lowering temperature will probably continue until the great southern ice-sheet closes the channel connecting the Atlantic and Pacific Oceans south of Cape Horn. The deepest portion of this strait is flanked on the north and south by shallow waters, extending east and west over a thousand miles ; and when we consider the immense fall of rain and snow in this region, which exceeds that of all other parts of the globe, excepting a few tropical places, it will be seen that the glaciers which now exist in the Southern Andes will, with a somewhat lower temperature, rapidly cover the plateaus of Patagonia and Chili, and even push out into the shoal waters which extend southward beyond the Falkland Islands and to a considerable distance south and west of the islands around Cape Horn. Therefore the conditions appear favorable for the glaciers of South America at some future time

to unite with the great southern ice-cap, and thus close the Cape Horn channel. This being effected, the westerly winds of the southern hemisphere sweeping over the southern ocean would cause an extensive low sea level to the leeward of Patagonia and the great ice barrier. This vast low level would extend eastward considerably beyond the meridian of the Cape of Good Hope, and, consequently, would attract the warm waters from the high levels of the tropical Atlantic and Indian Oceans well into the Southern seas; when the great process of melting the vast antarctic ice-sheet would commence. And this process would be considerably rapid, with the great tropical currents of the globe turned against it. Yet, the great ice barrier connecting South America with the antarctic ice-cap would be slow to melt away, on account of the frequent snow-storms of that region and because of its being situated to the windward of the tropical currents. The currents of air and water approaching this ice barrier from the westward, would lose much of their warmth during their long sweep along the ice-sheets lying south of the Pacific and Indian Oceans. Besides, we should consider that the upper portions of the great ice barrier would be so much elevated above the ocean, that only such parts as lie next the sea would be liable to thaw. Moreover, the polar cold on being subdued southward of the Atlantic and Indian oceans, would centre over the great ice barrier, because of its comparative inaccessibility to the warmth of the tropical surface currents; therefore, this ice barrier would be the most enduring ice of the seas and lowlands of the high southern latitudes.

While considering the climatic changes which have taken place in the high southern latitudes, it is well to realize what I have before indicated, that the warm waters from the tropical oceans cannot, at this date, penetrate far into the southern seas on account of the independent circulation of the Southern Ocean. This occurs when the tropical waters of the high ocean levels which lie abreast Brazil in the Atlantic, and the east coast of Africa in the Indian Oceans are not attracted far into the southern seas, because the surface

waters of the southern ocean are blown by the westerly winds continually around the globe; therefore, the tropical waters on reaching the latitudes where such winds and currents prevail, are turned away by them and are largely prevented from entering the cold southern seas. Yet it is evident that with an effectual barrier stretched north and south across the southern ocean, reaching from Patagonia to South Shetland, such as a great ice period would effect, the strong westerly winds would create a great low ocean level on the Atlantic side of the great barrier sufficient to attract the warm tropical waters, which are heaped against Brazil, and the east coast of Africa far into the southern seas. For as I have before explained, there is no other method through which the tropical ocean waters can penetrate the seas of the high latitudes sufficiently to bring about great changes of climate. Hence, it happens that on account of the independent circulation of the waters of the southern ocean the great southern ice-cap is constantly extending. Therefore, it is destined in the future to close on the southern extremity of the western continent, and thereby, through a simple process of nature, is shaping its own destruction. Meanwhile, from its gradual increase in weight, it is attracting so much of the waters of the globe towards it as is required to harmonize with the earth's changing centre of attraction. Consequently, many of the shoals and banks which are now covered by the seas of the high southern latitudes are drowned regions;* so that the islands of these seas have the appearance of being partly submerged. On the other hand, the extensive low lying plains of the northern hemisphere show unmistakable traces of having been at one time submerged by the sea; which fact goes to show that a portion of the ocean waters have withdrawn from the northern hemisphere

* While considering the great changes which have occurred in the ocean's level, we can conceive how the South Sea Islands have become peopled by men who seemingly had no adequate means of reaching such insulated parts of the globe as they have been found to inhabit. For it now appears evident that such detached shores have not always maintained the wide separation from other lands they now possess.

on account of being attracted into the southern ocean through the growing weight of the great antarctic ice-cap.

The effect that a large accumulation of ice around one of the poles would have for dislocating the earth's centre of gravity, I think has never been fully estimated. For it is not only the weight of the increasing ice-cap alone which moves the centre of gravity towards the ice-loaded pole, but also the immense amount of ocean water attracted by the ice-cap; which also adds its weight to the ice-burdened hemisphere, and probably exceeds the weight of the ice itself. Moreover, we should consider that the polar ice-sheet and the waters attracted towards it serve also to diminish the weight of water in the high latitudes of the opposite hemisphere in like proportion. Therefore, the movement of ocean waters from the high latitudes of one hemisphere to those of the opposite, seems to act with double power towards moving the earth's centre of attraction towards the ice-laden pole. The globe being largely covered by oceans of water, the effect produced by adding weight around one of the poles appears to be widely different from what would happen were the earth destitute of a fluid covering. Under the latter conditions, portions of the earth's surface taken from all parts of the globe and transported to one of the polar circles would probably dislocate its centre of gravity only in proportion to the weight so transferred, because the inert crust of the earth would not change its position in consequence. Hence, it appears that the weight of a polar ice-sheet with oceans of water at its command possesses far more power to change the earth's centre of gravity than it would without the great assistance derived from the mobility of the ocean waters. Moreover, in addition to the weight of polar ice-sheets for changing the earth's centre of gravity, another important agent should be considered which generally acts in connection with the polar ice for dislocating the earth's centre of attraction. The waters of the ocean, when forced by the winds under any circumstances from one hemisphere to another, must cause a dislocation of the earth's centre of gravity sufficient to prevent such waters from returning

through the action of gravitation. And it appears that at this age more water is carried into the high southern latitudes by the Mozambique, Brazil and Australian currents, than is carried north by the Gulf Stream and Japan currents; therefore, the greater weight of water thus moved into the southern latitudes by the action of winds must proportionally change the earth's centre of gravity sufficient to prevent its return northward through gravitation alone. And should this transfer of waters continue, it will in time drain the shallow seas of the northern latitudes.

I have shown how the submergence and uplifting of low lying continental lands have, at different eras, contributed to change the direction of great ocean-currents, and how such changes must be affected by polar ice-sheets. For the weight of the great antarctic ice-cap must have been the first cause of the ocean waters being attracted to the southern latitudes, sufficient for draining the Sahara Seas, and thus preventing the great equatorial currents of the Pacific and Indian oceans from having a direct passage to the Gulf Stream and through it to the northern seas. Therefore, it will be seen that the winds are also acting to move the northern waters southward, in addition to the weight of the growing southern ice-cap. The waters which in early periods passed through the Sahara Seas to swell the Gulf Stream, were largely supplied from the southern oceans; consequently, when this great tropical current, which carried water to the northern seas, was cut off from them through the uprising of the lands of northern Africa and turned southward, we can conceive the increased tendency of the world's waters towards the southern oceans. Thus, when we realize how the waters of the sea are being constantly moved by the attraction caused by polar ice-sheets, and also through the force of winds from one hemisphere to the other, and that the great mass of water so transferred must dislocate the earth's centre of gravity in proportion to its weight, it appears evident that it is the solid condition of the earth's crust, especially its land surface, which limits the changes in the earth's centre of attraction. For this reason, when we consider the vast northern seas which have already

been drained through the movement of ocean waters southward, and the consequent scantiness of the northern waters, it appears that the lands of the southern hemisphere cannot undergo a much wider submergence. Furthermore, the tendency of water southward may be considerably checked by the accumulation of ice on Greenland and other arctic shores; still, the great extent of southern seas where vapors form to be changed into ice, being superior to northern waters, and also on account of the currents setting northward from the equator being somewhat less than the currents running southward, it is probable that the submergence of southern lands will continue in a lessening degree so long as the weight of the southern ice-sheet is on the increase.

Although the views here advocated will not account for all of the apparent uprising and sinking of land which is said to have occurred in different parts of the earth (for it is asserted that several uprisings and depressions have taken place in the coast lines of different countries and some of them apparently within historical times; while nothing seems to be known of the laws which govern such movements), yet, apart from this, it is evident that accumulations of great masses of water occur alternately during long intervals of time around one and the other pole. The higher exposure of extensive lands which show traces of having been submerged, as we proceed northward from the tropic to the arctic latitudes, confirms this. Yet, we are told by some able writers to be cautious in attributing too much displacement to the attraction of glacial sheets. Professors Shaler and Davis in their interesting work on glaciers recommend this. Still, they are inclined to admit that the Adhemer hypothesis accounts for the greater part of the submergences and uprisings of land in the high latitudes. Nevertheless, while they call attention to the glaciation of the lands of the high latitudes, the known extent of such lands is shown on a chart. But the great southern ice-sheet, which is generally supposed to overrun nearly the antarctic circle, is represented as being a thin detached range of ice. This, we well know, is all that navigators have actually seen of this region. Still, we have

reliable evidence, sufficient to convince us, that the antarctic region is mostly covered by a heavy ice-sheet. The size and shape of the immense icebergs which break off and are set afloat from the ice-cliffs of this region, appear sufficient to prove such cliffs to be the edge of extensive ice-fields. I have met with these floating islands of ice, from two to three miles in length, and over a mile in width, and upwards of three hundred feet in height, with uniform flat tops. These huge cakes of ice which were probably three thousand feet thick, could not have formed on a narrow coast; but, from their great size and uniform flat tops, must have been broken off from extensive ice-sheets. As such ice-islands are found to be floating in great numbers for thousands of miles along the great southern ice-barrier, therefore it appears evident that the antarctic ice-fields extend far southward, for the same reason we should suppose that a river, which empties large quantities of water into the sea must possess an extensive water-shed, although we had only surveyed its mouth. Moreover, there is reason to suppose that such vapors of the Southern Ocean as are wafted to the antarctic circle are not all precipitated on its icy coast line; but that snow storms occur over the whole antarctic region. And as it is generally admitted that the northern half of North America and Europe was at one period overrun by heavy ice-sheets, this fact, and the circumstances connected with the southern ice-barrier, lead me to suppose that the antarctic region is now heavily capped with ice.

The changes which must have taken place in the outlines of lands and seas during the different stages of cold and mild periods can mostly be determined, because the solid parts of the earth, such as continents, islands, and extensive shoals and deep-sea basins, are slow to change their general form. Thus, should the lands of the high latitudes in both hemispheres be covered with heavy ice-sheets at the same time, the ocean waters would necessarily be at their lowest stage in the torrid zone, because of the immense amount of water stored in the ice-sheets. But should both northern and southern regions be mostly free from ice at the same time,

the ocean waters would correspondingly deepen at the equator. In such an event, the low-lying lands of the torrid zone would be flooded. Yet, it is obvious that the lands of the equatorial latitudes are not as subject to submergences and uprisings as the high latitudes. For should the high southern latitudes be loaded with ice, and the northern be comparatively free from frost, the southern lands would probably undergo a great submergence. While, on the other hand, should the antarctic regions be mostly free from ice, and the lands of the high northern latitudes be burdened with it, the ocean waters would be attracted towards the northern latitudes. Although, at this date, the ice is accumulating in the high latitudes of both hemispheres, it is not likely that the ice periods of the north and south will culminate at the same time, because the conditions necessary to bring it about are wanting. For it appears that when the great tropical currents are turned largely into the high latitudes of a hemisphere—through the causes which have been pointed out—it is evident that the tropical currents, entering the high latitudes of the opposite hemisphere, would be proportionally lessened; therefore, the process of melting the ice-sheets of the different hemispheres would occur more or less alternately. Still, both hemispheres might be heavily iced before the conditions necessary for melting the ice-sheets from the southern hemisphere could be brought about; because, as I have before shown, the tropical currents cannot reach the high southern latitudes until an ice barrier fills the Cape Horn channel and prevents the independent circulation of the Southern Ocean. The great low sea-level which the westerly winds would create to the leeward of the Cape Horn ice barrier, would attract the waters from the high sea-levels of the tropical oceans; consequently, when the tropical currents are thus turned into the Southern Ocean, the coldest periods would occur in the high latitudes of the north.

But when the southern ice-sheets were melted away and the lands of the northern latitudes were heavily burdened with ice, the earth's centre of attraction would, in conse-

quence, be moved northward, and the waters melted from the southern ice-sheets would be free to follow such attraction. It has been stated how, during such an event, the low lands of Northern Africa would be submerged, and, consequently, the great tropical currents of the Pacific and Indian Oceans would find their way directly into the North Atlantic, and so add their warmth to the Gulf Stream. Therefore, we can well account for the heat which would melt the great northern ice-sheets and raise the temperature of the whole Arctic region. For, under such conditions, the North Atlantic and Arctic Seas would be the reservoir for a large portion of the conserved heat of the tropical waters of the globe. Moreover, the great equatorial currents of the Indian Ocean having a free course across Africa to the northern seas, would not only carry large quantities of heat from the southern oceans, but a portion of their weight and bulk also, so that the shallow seas of the high southern latitudes would become dry land. Meanwhile, the gradually lowering temperature of the southern regions would again have an ice-sheet collecting around the south pole, which would in time gain weight sufficient to drain the shallow seas of Northern Africa, and so cut off the great tropical currents from the North Atlantic and Arctic waters, so that ice would again gather on lands in the high northern latitudes, and thus create the climatic conditions which are maintained to-day.

It will be seen that my explanation of the great climatic changes in the high latitudes also accounts for the warm climate of the carboniferous ages. The warmth required for such periods could scarcely have been supplied by an ocean as limited and insulated as the Atlantic of the present time. But when we consider that the tropical oceans during the carboniferous age evidently did maintain a higher sea-level than now; or, at all events, the beds of the Sahara seas stood at a considerable less elevation than now, their channels having been since raised by immense calcareous deposits and by the drifting sands of the desert, it follows that the warm equatorial currents from the Indian Ocean must have had a free passage through the African seas into the North

Atlantic. Thus, we can well account for the continuous warm climate which existed during the forming of the coal-beds on the eastern slope of North America and the shores of Great Britain. During this age, it is probable that both hemispheres were mostly free from ice; which accounts for the ancient tropical seas being supplied with water. Thus, it would follow that the Cape Horn channel would be so greatly reduced as partly to destroy the independent circulation of the Southern Ocean. Consequently, so long as such conditions lasted, the ice would not form in immense sheets around the poles. And it seems that the first ice periods must have happened in the Antarctic regions, when the independent circulation of the southern seas were the least obstructed. But it is probable that all of the early southern ice-caps were not of sufficient weight to drain the Sahara sea, yet were able to lay bare at different periods the carboniferous lands of North America and Great Britain. The ice-sheets of early ages must have scoured the Cape Horn channel and caused it to become much enlarged, consequently giving a more independent circulation to waters of the Southern Ocean. Therefore, the southern ice-sheets of later periods were more extensive than those of an earlier age, because the widened channel required larger ice-sheets to close it. In this manner the southern ice-sheets at length obtained sufficient weight to drain completely the Sahara seas, and so prevented the direct flow of warm water from the Indian Ocean into the Gulf Stream. Thus, the heat of the tropical Atlantic currents was reduced sufficiently to render them unable to prevent the Arctic seas from chilling. Nevertheless, under the conditions I have stated, the great forces of nature may have caused ice-sheets to form in the high latitudes of the north in ages prior to the carboniferous era. For it is reported that conglomerate occurs with boulders deposited previous to the formation of coal-beds, which appears to show the action of ice, and that an ice-burdened southern hemisphere was able to drain the Sahara seas and deprive the North Atlantic for a period of its greatest source of heat prior to the carboniferous age.

Writers have thought, while considering the wide extent of the low lying lands which show certain traces of having been submerged at different eras, that the oceans to-day contain less water than during earlier periods. They think that the earth's crust may have absorbed a portion of the ancient ocean waters; or that the great sea basins have deepened somewhat and thus lowered the general level of the sea. And it appears reasonable to suppose that such changes may have happened, and that the ocean now lacks water sufficient to again overflow the wide lands which were once the beds of vast seas. Yet, under certain conditions, it appears that there is still water sufficient in the sea to flood the greater part, and perhaps all, of the lands which during remote ages were covered with water. The explanations given in the preceding pages show how the ocean waters have submerged the low lands of the high latitudes during different periods, but they fail to explain the great Amazon valley, which, according to the explanations of Professor Agassiz and other geologists, has been flooded by the sea during past ages. The water now contained in the polar ice-sheets, even if entirely melted and equally distributed over the oceans at the present time, certainly would not be adequate to raise the waters of the equatorial oceans sufficiently to submerge the great Amazon valley. Still, as I have pointed out, the conditions which would be brought about through the melting of the Antarctic ice-sheets, and the gathering of heavy ice-sheets in the north, would result in the submergence of the low lands of Northern Africa, and through such means so distribute the ocean waters as to flood the low valleys opening on the North Atlantic, especially during the melting of the northern ice-sheets. The great Southern Ocean which now covers so large a portion of the high southern latitudes, on being attracted northward, would, at a certain stage, be very evenly distributed over the different latitudes of the earth; and during such a distribution of the ocean waters, the Amazon valley would probably be flooded to some extent. And it appears that the large amount of water which would be moved by the prevailing winds from

the Indian and South Pacific Oceans into the Atlantic through the seas of Northern Africa, would change the earth's centre of attraction somewhat towards the Atlantic side of the globe. For we should consider that water possesses weight. Consequently, when the ocean waters are moved by the action of winds from one side of the globe to the other side, such waters cannot return by gravitation, because of the earth's centre of attraction being dislocated in proportion to the weight of water so moved. Besides, we should bear in mind that the great American continent would serve as a barrier against the return of such waters towards the west. Thus, when we realize the great amount of water which has been moved into the Atlantic by the great prevailing winds, and how the area of its surface was thus increased over one-third above its present size, and also that the great ice-sheets of the northern latitudes were at the same time mostly situated on the Atlantic side of the north pole, it is plain, from the great gathering of water and ice on the North Atlantic and its shores, that the earth's centre of attraction must have been moved towards the centre of such gathered weight of water and ice. Hence, all low valleys opening into the North Atlantic were flooded by the sea, even to the equatorial regions; therefore, the great Amazon valley would also be submerged.* During such a period, it will be seen that, as the seas around Southern Australia and New Zealand were situated on the opposite side of the globe from the enlarged North Atlantic, their waters must have become shallow because of being moved away by the united action of winds and gravitation to swell the North Atlantic seas. Yet, such an immense transfer of ocean water from one hemisphere to the other was accomplished with no more disturbance in the general operations

* It is probable that during such times the lower valleys of Central America may have formed narrow straits leading from the Atlantic into the Pacific. But that portion of the Pacific maintains a higher sea-level than the seas abreast Peru and Mexico, because the winds blow towards it from every direction; therefore, should straits be opened through Central America, they would only connect one high ocean-level with another.

of nature than is taking place to-day, because of the great length of time the performing agents consumed in bringing it about, while the permanency of such work compared well with the time required to accomplish it. For, during such times, suppose the atmosphere should cease to act on the sea, either through air-currents or other of its disturbing agents, it is not probable that the increased waters of the Atlantic would return through the action of gravitation to the reduced southern seas, from which they had been moved by winds through convenient channels, and also by gravitation through the weight of ice-sheets on the North Atlantic and Arctic shores, from the fact that the earth's centre of gravity changes just in proportion to the weight of waters so transferred. Of course, the high and low sea-levels of the North Atlantic, caused by winds limited to its own waters, would soon assume a common level, and so also would the high and low sea-levels so caused on other oceans. But the waters of a hemisphere would not return through the action of gravitation to the opposite hemisphere from which they had been previously moved by the attraction of ice-sheets in connection with winds, because the earth's centre of attraction would be already adjusted to the position of such waters. In order for such waters to return from the North Atlantic and Arctic seas to the Southern Ocean, the ice-sheets would first have to be melted from the northern lands and gather on the lands of the Antarctic regions sufficient to attract the ocean waters southward, and so drain the shallow northern seas.

The location of the greater portion of the ocean waters on the earth at this date, shows how such waters can submerge the greater part of the southern hemisphere, and still be in perfect harmony with the laws of gravitation. And with the constant gathering of southern ice-sheets, and the tendency of prevailing winds, in connection with land, to move more of the ocean waters southward than they move northward, it is probable that the southern lands will undergo a still greater submergence. The terraces which mark the bounds of ancient seas in Patagonia and New Zealand, show

that such has been the condition of southern lands in the remote past. With this movement of ocean waters southward, the shallow seas of the northern latitudes, such as the North Sea and Baltic and the Grand Banks of Newfoundland, will, in time, be destitute of water, as they undoubtedly have been in the remote ages of the past. And yet, with all those changes, the waters of the ocean will still retain the same harmony with the laws of gravitation that they possess at the present time.

Since the existence of ice periods has been geologically proved to have possessed the high latitudes at wide intervals, and separated by eras of temperate weather, various theories have been advanced to explain the causes which may have produced them, and also to account for the great submergences and uprisings of low-lying lands. Some writers have imagined that a change in the position of the earth's axis of rotation, due to the elevation of extensive mountain tracts somewhere between the poles and the equator, must have caused the great climatic changes which have left such abundant traces on the lands of the high latitudes. But it has been ascertained that the protuberance of the earth at the equator so vastly exceeds that of mountain ranges or table lands on the globe, that only slight changes could have resulted from such causes. It has also been surmised that during the ice period the lands in the high latitudes of the northern hemisphere stood at a higher level than at present, and, consequently, became iced like the highest mountains of the present time. But there is no proof that the lands attained a much higher altitude than now. On the contrary, all the evidence goes to show that large tracts of lands in the northern hemisphere were submerged during the ice period.

The theory so ably explained by Sir Charles Lyell, was, for a time, favorably received. Lyell conceived that if lands were massed chiefly in the tropics, the climate of the globe would be such that tree-ferns might grow luxuriantly on any islands that might lie within the Arctic or Antarctic circle. For he supposed that the heated lands would give

rise to warm winds which would sweep north and south, carrying with them the heat of the tropics, and thus temper the climate of the higher latitudes. On the other hand, were the lands to be grouped chiefly around the poles, the reverse of all this would happen. For with no land under the equator to receive the heat of the sun, and give it to the winds to carry north and south, the climates of the high latitudes would be so greatly affected that snow and ice would gather upon the ground and gradually creep down to the lower latitudes. Thus, the atmosphere is represented to be the chief medium by which heat derived from the sun is carried from one latitude to another. But this explanation has been generally abandoned, because, after a careful examination, ocean currents, although caused by winds, have proved to be the greatest carriers of heat from the tropics to the high latitudes. Moreover, there is nothing to show that there has been any great change in the position of continents during the periods of frigid and mild temperatures which have existed in the high latitudes. Professor James Geikie, in his writings on climatic changes, says that it is quite certain that no one can show that the glacial climate, which at different periods spread over the northern temperate zone, was induced by any peculiar arrangement of land and sea. This statement was intended to show that there had been no great changes in the situation of continents and large islands, and is not antagonistic to the explanations I have advanced; on the contrary, the interesting facts promulgated in his writings on climatic changes have been a valuable aid in my explanations.

Professor Tyndall, while alluding to the great ice age, says, "I have no new hypothesis, but it seems possible to give a truer direction and more definite aim to our inquiries. The aim of all writers on this subject with whom I am acquainted, has been directed to the attainment of cold. Some eminent men have thought, and still think, that the reduction of temperature during the glacier epoch was due to a temporary diminution of solar radiation; others have thought that in its motion through space our system may

have traversed regions of low temperature, and that during its passage through those regions the ancient glaciers were produced; others, with greater correctness, have sought to lower the temperature by a redistribution of land and water. For to create glaciers requires the operation of heat as well as the Arctic cold." Thus it will be seen that the statements of this discerning scientist are in harmony with my views, while his writings on meteorology are regarded as one of their firm supports.

One of the latest, most deeply-studied and widely-accepted theories which has been propounded to account for the great climatic changes which have taken place on the earth at wide intervals of time is by Dr. Croll, a high authority on the subject, who gives this explanation: "When the eccentricity of the earth's orbit is of high value, and the northern winter solstice is in perihelion, agencies are brought into operation which make the south-east trade-winds stronger than the north-east, and compel them to blow over the northern hemisphere as far, probably, as the Tropic of Cancer. The result is, that all the great equatorial waters of the ocean are impelled into the northern hemisphere, which thus, in consequence of the immense accumulation of warm water, has its temperature raised, and snow and ice, to a great extent, must then disappear from the Arctic regions. When the procession of the equinoxes brings around the northern winter solstice to aphelion, the condition of things on the two hemispheres is reversed, and the north-east trade-winds then blow over upon the southern hemisphere, carrying the great equatorial currents along with them. The warm water being thus wholly withdrawn from the northern hemisphere, its temperature sinks enormously, and snow and ice begin to accumulate in the temperate regions. The amount of precipitation in the form of snow in temperate regions is, at the same time, greatly increased by the excess of evaporation in low latitudes, resulting from the nearness of the sun in perihelion during summer. The final result, therefore, is that these warm and cold periods which have alternately prevailed during past ages, are simply the great

secular summers and winters of our globe, depending as truly as the annual ones do upon planetary motions."

However ingenious and plausible this theory may appear, and however widely accepted it may be by persons interested in such matters, it is not in harmony with well-known natural laws, or with historical records of climatic changes. Eminent astronomical writers have stated that no appreciable change of climate could possibly result from any variation in the eccentricity of the earth's orbit. The earth, they maintain, receives the same total amount of heat in the aphelion, as in the perihelion, section of its orbit. This we know is due to the fact that our globe moves with less speed at aphelion than it does in perihelion; therefore, in aphelion the greater distance of the earth from the sun is exactly counter-balanced by the longer time the globe is exposed to the solar rays. Consequently, it does not matter to what extent the eccentricity of the orbit may vary, the equal distribution of the sun's heat must continue invariable. These arguments have been found to agree so well with ascertained facts that it is not probable they can be controverted. Therefore, Dr. Croll's explanations cannot be accepted while we realize that the tropical waters constantly receive the same amount of heat from the sun's rays during the year, whatever variation there may be in the eccentricity of the earth's orbit. Besides, it would not seem possible for the trade-winds to blow the equatorial surface-waters northward across the Tropic of Cancer, with a vertical sun at perihelion in the southern hemisphere. For the great tropical wind belt is well known to be governed largely by the sun's declination, and it seems certain that solar heat would lose none of its power for controlling the winds with the sun at perihelion. Hence, it appears that it would be impossible for the tropical winds to blow the equatorial surface-waters much beyond their usual limits into either of the hemispheres. Dr. Croll also asserts that the ice periods of the northern and southern latitudes occur alternately; consequently, the ice-sheets of the northern hemisphere would have to be melted by the sun's rays alone before the tem-

perature could be raised sufficiently to attract the tropical winds northward and impel the waters into the northern seas. With the great plains of North America and Europe covered with ice-sheets, the warm surface-winds of the tropical oceans would not be attracted towards them. The ice gathered on these lands on account of the tropical currents being turned away from the northern oceans, consequently the sun's rays alone could not prevent the ice from gathering, neither could the sun's rays melt such ice away without first having assistance from the heated waters of the tropical seas.

I have before explained that there is apparently only one effectual way through which Nature forces the currents of the sea with sufficient rapidity from one zone to another, so as to change their temperature to any great degree; such work being accomplished through great prevailing winds blowing the waters of the different zones to and from continental barriers, thereby changing the level of the sea sufficient to cause great surface currents to run from one zone to another, in the manner I have pointed out as being carried on in the northern and southern hemispheres.

I think that Dr. Croll rightly assumes that the winds are the principal cause of ocean currents, and also that they are not due to the trade-winds alone, as was recently supposed by the advocates of the wind theory, but to the general impulse of the prevailing winds of the globe.

Dr. Croll also declares that "all the principal currents of the globe are moving in the exact direction which they ought to move, assuming the winds to be the sole impelling cause." This general agreement between the system of winds and of great ocean currents, he illustrates on a chart. But the direction of winds as laid down on this chart does not correspond with the well-known prevailing direction of winds which blow over the Atlantic from Florida to Newfoundland. According to Dr. Croll's showing, the Gulf Stream is impelled along the shores of the United States by a prevailing wind blowing its surface waters along in the same manner that the trade-winds force the tropical Atlantic

waters from the eastern to the western side of the ocean. But this is not so to any great degree; because the trade-winds which blow the tropical Atlantic waters from the east into the Gulf of Mexico, do not turn north with the Gulf Stream along the shores of the United States; their irregular northern movements being largely diffused over the great Mississippi Valley until they blend with the great westerly wind-belt of the high latitudes. Consequently there is no prevailing wind blowing the Gulf waters from Florida to seas abreast Newfoundland. On the contrary, the strong westerly winds which have the most effect on the western Atlantic waters are from the north of west. They merely blow the surface waters away from the American coast, so that the waters of the high sea level of the Gulf of Mexico are attracted along the eastern coast of the United States, because of the low sea level occasioned by the westerly winds. Still, the westerly winds do not force the surface waters of the Atlantic away from the American coast continuously, in the manner the trade winds are seen to force the tropical surface waters away from the coast of Sahara, for the westerly winds blow by spells; and it is because of intervening lulls, and the changing of the winds, that the Gulf waters are prevented from being blown much further from the American coasts than they now are found. The great stream of gulf water, during the intervals of light or varying winds, is attracted directly along the low sea level of the Atlantic where not crowded off by the arctic currents, so that the strong westerly gales can only drive its surface waters eastward. Still, as I have before stated, the strong winter gales, with the help of arctic currents, do force the surface waters of the Gulf Stream eastward hundreds of miles away from the position they maintain during the summer abreast Greenland. Yet, it is probable that the deeper portion of the gulf currents maintain their position in under-currents, and are only thinly covered by the drifting surface waters of the arctic seas which sweep down from the north, and assist the westerly winds in forcing the Gulf Stream off

shore. Thus I insist that the tropical waters are moved from their high sea levels into the high latitudes mainly by the attraction caused through the westerly winds creating low sea levels, by sweeping the surface waters of the ocean away from the extended shores of continents.

Dr. Croll refers the glacial epoch to the last great increase of the ellipticity of the earth's orbit, which began some 240,000 years ago and ended about 80,000 years ago. The cold was supposed to be the most intense about 200,000 years ago. But even the latest of these dates appears too distant to include the latest ice period. For when we consider the scant deposits which have collected from vegetation, on lands once overrun by glaciers, it appears that the last great northern ice-period must have ended at a later date than above estimated. The general appearance of lands once overrun by ice-sheets shows this. The lands of New England abound with hollows from which there is no surface drainage. Yet these depressions show a remarkable scantiness of vegetable mould where the water-shed sloping into them is not extensive. Even should these lands have been left bare of vegetation by the glaciers, yet the warm climate which melted the ice away probably was the means of soon covering the country with grasses and forests. But it may be that certain species of hardy plants flourished for a considerable time before the ice-sheets melted away. Lieut. W. H. Dall reports that on the shores around Point Barrow certain kinds of vegetation were very dense. Yet, the scanty soil on which they grew rested on a stratum of pure ice of unknown depth.* Thus, from the above considerations,

* This fact appears to show that extensive ice-sheets do not always consist of one compact layer of ice, but that the upper portions at times flow over the lower, thus forming separate sheets of ice. The upper stratum being exposed to the sun's rays becomes more heated than the lower ice; and, as the heated ice is very susceptible to the action of gravity, therefore, the upper ice has the greater motion, and, through this cause, carries the débris from the higher lands over the lower ice-sheet. This is the opinion of Professor James Geikie, who also says that the upper stratum of ice not only moves faster, but also in a different direction from the lower ice. As the upper ice-sheets move and melt away, faster than the lower, thus the underlying stratum in one stage of its existence would represent the same conditions of the lands about Point Barrow.

it appears that Dr. Croll's explanations place the last great ice period much too far back in time, and also fail to point out the main cause of tropical waters entering the high latitudes; he also neglects to explain why the temperature of Greenland, Iceland, and other countries, situated in high northern latitudes, is slowly lowering. On the contrary, according to his theory their climate should be growing warmer. But we learn from their history that for the last eight hundred years the temperature has been gradually lowering, although the northern winter solstice is in perihelion.

Professor James Geikie, in his work entitled "The Great Ice Age," asserted that there was no evidence whatever of a warm post-glacial period; but in his more recent writings on "Pre-historic Europe," he says the above statement was too broad, and he is inclined to the opinion that the climate of the post-glacial epoch was for some time marked by a more genial temperature than we now enjoy. But it is no doubt true that no such period of warmth has been maintained in post-glacial times as existed in pre-glacial and inter-glacial epochs, when the coal-beds were deposited, or such warm periods as attracted the hippopotamus, the elephant, and the rhinoceros, to roam over Britain. Still, I think that the mild climate which melted away the ice-sheets of the last great ice period was warmer, even after the ice disappeared, than the climate of modern times, and that it may have continued mild for a considerable length of time before the ice began to gather again on the low lands of the Arctic regions. Centuries ago, the climate of Scotland was more favorable for the growth of heavy timber than it now is; tradition and history lead me to this belief, while the remains of ancient forests confirm it. In the northern districts, and also the islands of Orkney, Shetland, and the Hebrides, now bare of living timber, prostrate forests are found covered with growing peat. These forests, which flourished since the last ice period, covering the low grounds and in many places the hill-tops, must have grown in a milder climate than that of to-day. During the last four

or five centuries, the climate of Northern Scotland and its islands has evidently been so inclement as to favor the growth of bog-mosses, which now overwhelm the prostrate timber. When the Romans invaded Great Britain, it is said that its northern lands were much better wooded than now; therefore, the probability is that hundreds of years ago the climate was somewhat warmer than the climate of to-day. Some species of the timber which now underlies the peat-moss indicates that a drier, as well as a warmer, climate prevailed at the time of its growth than that of the present. This seems to indicate that the lands of Great Britain, when exposed to a higher temperature, did not condense the passing Atlantic vapors so readily as the colder lands of later years. The numerous half-savage tribes which inhabited Northern Europe two thousand years ago could hardly have gained a subsistence in a climate as rigorous as that of the present time. The imperfect modes of agriculture, and improvident habits generally pursued by such people, seem to show that those earlier tribes must have lived in a milder climate than their civilized descendants have enjoyed during the last century.

Yet, whatever increase of cold there may have been in the high northern latitudes, there does not appear to be any decided increase in the glaciers of mountain ranges situated in the temperate zone. The Alpine glaciers, so far as I am informed, have shown no general retreat or advance during recent years. Even in the neighboring valleys some glaciers will be falling back while others are pushing their fronts down to lower levels. But on Greenland, and the extensive regions north of Hudson Bay, it is probable that the snow and ice is on the increase, because such lands are removed from the influence of the Gulf Stream. Greenland seems to have been far more free from ice at the time of its discovery than now; it having received its name from the Northmen because of its abundant verdure. Travellers visiting Iceland say that the old accounts of its prosperity seem strange to those who now visit its shores. And it is narrated in the Sagas that in early times sheep could shift for themselves

during winter, and that there were large forests and that corn ripened.

Ireland during the last generation has been subject to inclement seasons and poor harvests. And there is no doubt that the agricultural failures of Great Britain have been much relieved during the last century through the great increase of manufactures. The early fall rains which injure the harvests, show that the cold lands condense the passing vapors more readily than in earlier times.

The climate of Northern Europe has long been accused of growing colder. The vine no longer flourishes on the shores of Bristol Channel, or in Flanders or Brittany, and vineyards are no longer planted on the elevated lands of France, where they flourished three hundred years ago. Arago did not refuse to believe that the laws regulating the temperature of Western Europe had notably altered; this is proved, he said, by the general retrogradation of the vineyards towards the south. In Sweden, it is said that spring commences fifteen days later than it did in the last century. In some countries where the people live mostly by agriculture, an increase of inclement weather promotes emigration to such an extent as to lessen the population. Ireland affords an example in support of this statement. A correspondent of the *Spectator* writes from Northern Russia, where the Volga is locked with ice for six months of the year, that "the people are beginning to show increased resentment at the climate, and that there is reason to believe that the northern government of Russia will be abandoned to the desert. The people silently glide south by scores of thousands every year, till the life of Russia is concentrating in the south." Thus it appears from such reports that the cold is slowly on the increase in countries situated in high northern latitudes.

I have explained how the increase of cold in the high latitudes is caused through the failure of tropical currents to penetrate far into the Northern and Southern Oceans, on account of the independent circulation of their waters. I have also pointed out how the Southern Ocean has an inde-

pendent circulation through its surface-waters being swept constantly around the globe by the prevailing westerly winds; and how, through this cause, the ice is gathering around the south pole. I have also shown how the Arctic waters are circulated by the westerly winds; and how their currents largely force the Gulf Stream from the higher latitudes, and how this is one great cause of ice gathering in the Arctic regions, and the consequent increasing coldness of the high northern latitudes.

Great changes in the temperature of different parts of the earth are thus slowly and constantly being brought about, although the heat which passes from the sun to the earth does not vary with the changing temperatures. Yet when we consider how under favorable conditions solar heat may be preserved and distributed by the ocean waters over all seas, we find that such heat is sufficient when so preserved and distributed to prevent ice from gathering on the lowlands of any part of the globe. This I have shown could be accomplished by a continuous barrier extending north and south dividing the ocean waters from the arctic to the antarctic circle, sufficient to prevent the independent circulation of the waters of the different zones. The waters of these separate zones, when blown to and from such a continuous barrier, must cause an unevenness in the ocean's level sufficient to mingle the surface waters of the different latitudes; that is, the high levels of the tropical oceans would seek the low ocean levels of the high latitudes, and so carry tropical heat even into the polar regions. Still, apart from the action of gravitation to move thus the ocean waters from one zone to another, I am well aware that the winds often directly assist in the work. For we see the winds blowing towards the south along the southern coast of Brazil, and thus assisting the Brazil current on its way to the low sea-level abreast of Patagonia. We also see the southerly winds frequently assisting the Japan current. But such winds, although blowing away from the equator, are largely spread over the land, and consequently are not competent to drive the swift currents which are moved principally by

the action of gravity from the equatorial regions to the high latitudes. Thus it follows that whenever the high latitudes of a hemisphere have tropical heat so transferred to them, the winds of such regions should be more uniform and less boisterous, on account of there being no great extremes of heat and cold existing in the different zones. Moreover, under such conditions the easterly tropical winds which, as I have explained, are largely moved by the attraction which follows the sun, would, after crossing an ocean, be attracted towards the warm lands of the high latitudes, which would be an additional source of heat to the countries situated within them. But should the great barrier which caused the mingling of the ocean waters be removed in the high latitudes of a hemisphere, the prevailing westerly winds would sweep the surface waters of such latitudes constantly around the globe, and so prevent the tropical currents from reaching the colder zones. Consequently, these zones being deprived of the heat of the tropical oceans would in time so lower their temperature that snow and ice would gather on the lands situated within them; and when the ice had spread extensively over such lands, the sun could no longer heat them, because the solar rays would be largely reflected into space, or else used up in melting the snow and ice. Thus comparatively little of the solar heat would find its way into the atmosphere by radiation, and moreover the tropical winds would no longer be attracted into the high latitudes because of the low temperature of their lands and seas. On the contrary, the cold, heavy air of the high latitudes would be more generally attracted towards the tropical zone, and consequently narrow the limits of the tropical wind belt. And should the exclusion of tropical winds and waters from the high latitudes occur largely in both hemispheres at the same time, the winds of the tropics would probably be governed largely by equatorial heat, instead of following the attraction which follows the sun, inasmuch as such winds are mostly sent aloft and deprived of their heat within the tropics, hence they would reach the higher latitudes only in cold upper air currents. In fact, the great currents of the atmosphere and

ocean would work to extend a low temperature over the greater portion of the globe. When the temperature of the high latitudes of a hemisphere is reduced in the manner above described, the winds of such latitudes increase in boisterousness because of the great disparity of heat and cold existing between the tropics and high latitudes. We see how winds increase in violence on the approach of winter in the temperate zone, and so continue with brief intervals until the approach of summer, when more gentle winds prevail. The temperature of the southern ocean being gradually lowered, because of the antarctic ice-sheets having attained considerable dimensions, and also owing to the independent circulation of its waters, the summer winds of the high southern latitudes are far more boisterous than the summer winds of the high northern latitudes, where the oceans are better warmed by the tropical currents. This fact makes it appear that the gradually lowering temperature of the high northern latitudes proportionally increases the ruggedness of the northern oceans. And it seems that the oceans in the temperate zones are more boisterous in both hemispheres than in the days of the early navigators. Many old seamen are of the opinion that such seas have increased in ruggedness during their own experience.

The tropical heat which is now carried into the high latitudes of the northern hemisphere and sustains a temperate climate over the larger portion of their lands and seas, is mainly furnished by the tropical Pacific and Atlantic Oceans. The Pacific Ocean, having no wide communication with the Arctic seas, has comparatively little to do with bringing about ice periods, or warm eras of temperature in the high northern latitudes; although, during an ice period, it furnishes vapor sufficient to cover the great north-western region of America with an ice sheet. The temperature of this vast region is raised in a great degree by the warmth of the north Pacific waters, so long as the ice sheets do not possess its lands.

At this age, the direction of the North Pacific winds, as I have before remarked, must affect the temperature of the

North American winters, because the winds control the ocean-currents. For should the westerly winds of the North Pacific blow more from the northward than usual during the winter season, the tropical currents would fail to carry the usual amount of heat to the north-western coast of America, and the temperature of the country would be lowered in consequence. Hence, it is the irregular action of the winds that causes the temperature of different years to be somewhat unlike in the United States and British America.

I have pointed out how the Atlantic Ocean, with its wide connection with the Arctic seas, under certain conditions, sends its tropical currents far into the polar regions; and I have also shown how the northern regions are chilled through the Arctic currents forcing the Gulf Stream southward; I have explained, too, how this great carrier of heat has been reduced since the ending of the last northern ice period, through the disappearance of the great Sahara Sea, and the consequent separation of the North Atlantic from the direct flow of the great equatorial currents of the Pacific and Indian Oceans. Yet, we should consider that the tropical heat of these oceans has been able to reach the Atlantic in a diminishing stream through a branch of the Mozambique current—called, at the Cape of Good Hope, the Agulhas current, which at times runs a large stream of warm water into the Atlantic, being attracted by the low ocean-level abreast the west coast of southern Africa, whence it is blown by the south-east trade-winds toward the tropical Atlantic, and so raises the temperature of its waters. But even this single source of heat from the great tropical oceans of the world is being gradually subdued, from the constant lowering temperature of the high southern latitudes. For, while the temperature lowers, the westerly winds encroach proportionally on the lower latitudes and thus prevent the waters of the Agulhas current from passing around Africa into the Atlantic. During the summer the easterly winds yet prevail to a considerable extent along the coast of the Cape Colony. But the forces of the Agulhas current and the antarctic current are so evenly balanced, that during the prevalence of an

easterly wind the warm Agulhas current flows around southern Africa from the Indian Ocean into the Atlantic. But, when the westerly winds prevail, the waters are turned back and made to flow eastward. At such times the cold drift currents of the southern ocean prevail along the coasts of southern Africa. But, in addition to the Agulhas current, the Atlantic also derives considerable heat from the great tropical rivers which empty into it. The Congo, Niger, Amazon, Orinoco, and many other large streams, add their warmth to its surface waters which contribute to the Gulf Stream. The largest rivers of North America, Europe, and northern Asia, also add their summer warmth to its northern waters. Consequently, the increase of cold in the high northern latitudes is necessarily slow. For the Gulf Stream will continue to flow into the high latitudes, with little decrease in temperature and volume, until the southern ice sheets fill the Cape Horn channel. But when that remote event takes place, the tropical Atlantic currents will be mostly turned into the southern ocean. Consequently, during such times the climate of the high northern latitudes will be exceedingly cold. But before this frigid period can be brought about, some limited portions of the northern regions may undergo considerable climatic changes, from the fact that the independent circulation of the Arctic seas may be interrupted by glaciers, or their channels may be deprived of water through the movement of the ocean waters into the southern hemisphere, which I have indicated to be now slowly progressing. Under such conditions, the arctic currents could no longer force the Gulf Stream southward; therefore, its warm currents, although diminished in volume, would still wash the shores in the region of the British Isles, which would then form a part of the continent; so that the climate in that locality would compare with the climate of Norway at the present time. But because of the complete exclusion of the tropical waters from the arctic regions, on account of Behring Strait and the shallow sea between Norway and Iceland being destitute of water, therefore a large portion of northern Europe, Asia, the northern parts of North America, and the

whole arctic region, would experience a low temperature. Professor Geikie thinks that there are traces of a climate having existed since the last ice period favorable for the growth of certain species of trees in the region of the British Isles at the time when the bed of the North Sea was a vast plain traversed from south to north by a great river, which carried the tribute of the Thames and Rhine and other streams into the northern ocean. The sunk forests which abound along the northern shores of France and the Channel Islands, and the submerged peat which is found off the shores of Great Britain and also in the North Sea, appear to support this view. Still, my opinion is, that if these remnants of submerged forests and peat-bogs grew where they are now deposited, it must have been prior to the last ice period, when the ocean waters were largely gathered in the southern hemisphere. For when the Cape Horn channel was closed by the southern ice-cap, the tropical currents of the Atlantic were attracted southward to such a degree that ice-sheets commenced to form on all of the lands of northeastern Europe, and, consequently, after a considerable time, the ice which covered the lower valleys and plains was overridden by ice sheets from higher lands; therefore, the ice-covered forests and bogs of the low lands were prevented to a considerable extent from being carried into the deep ocean, because the lower stratum of ice on account of the level condition of the lower lands in many places remained nearly stationary, while the upper stratum, being exposed to the sun's rays and rendered susceptible to the action of gravity, moved to the sea in such directions as presented the last obstruction. Still, we should consider that there is no certainty of these remnants of submerged forests and peat-bogs having grown in the localities where they are now found; for they may have been moved down from higher situations by ice-sheets during the last ice period and deposited where they are now found. Either of the above explanations seems probable, as such deposits are generally covered by a layer of sand.

The reason why I suppose either one or the other of the

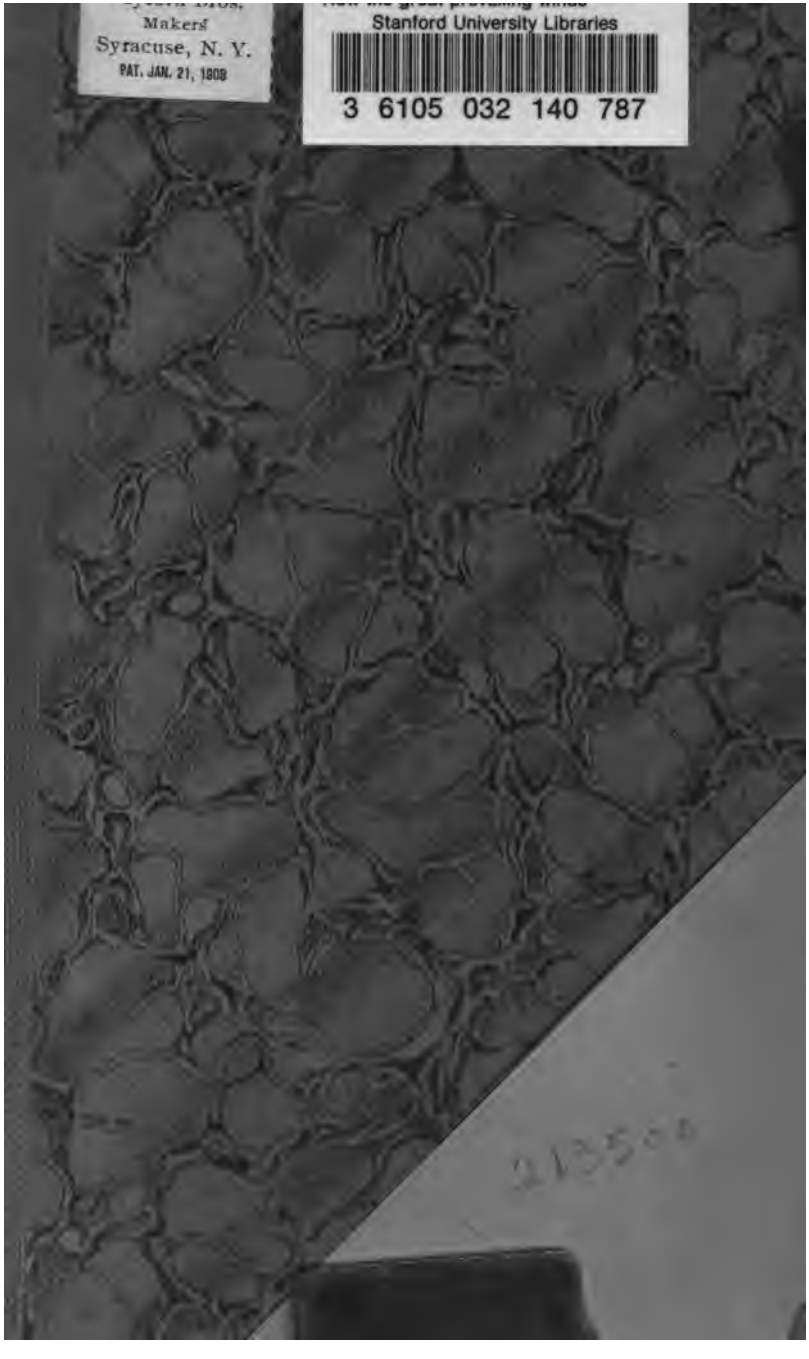
above agencies account for the existence of submerged bogs and forests, is because I cannot conceive how the beds of the British channels and the North Sea could have been raised above the ocean at any time since the last northern ice age. This will be seen from the explanations I have given, which maintain that the waters of the northern latitudes have been gradually moving into the southern hemisphere since the last ice period. That these mysterious forces by which the solid crust of the earth is elevated and depressed, have acted to raise above the sea and again submerge such a vast region during post-glacial times, would be subject to considerable doubt among those who believe that the solid structure of the earth is unfavorable for the occurrence of great depressions and upraisings in its crust. Therefore, I prefer to attribute extensive shiftings in the distribution of land and sea to the agencies I have set forth in the preceding pages, especially if they are found to harmonize with the physical structure of the earth as it exists to-day.

At an early age the Isthmus of Suez and the low lands of Sahara were below the surface of the sea, with the oceans of the northern latitudes at their present level. This is proved by the gealogical features of these regions. The beds of the ancient seas of northern Africa have been raised during later periods by immense calcareous deposits, and their basins filled by sands and clays from large rivers; and, furthermore, the low lands of Suez have been for ages an area of deposit for the sands blown from the neighboring deserts. Therefore this once submerged region may have been so much raised from the above causes that the tropical Indian Ocean waters will in the future be considerably more debarred than in times past from entering the North Atlantic. Consequently, the Arctic regions may never again experience the long periods of warm weather which prevailed during the earlier ancient eras. Moreover, the vast deposits which now cover the lower portions of the Suez region were the means of raising its lands above the ocean's level so soon after the last great northern ice period, as early to shut off the warm Indian Ocean waters from the North Atlantic.

On this account, the era of high temperature which must have followed the earlier ice periods did not prevail in the high northern latitudes to any great extent after the ending of the last northern ice period.






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